Heat transfer in natural recirculation reboilers: the effect of gravitational forces

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HEAT TRANSFER IN NATURAL CIRCULATION REBOILERS:
THE EFFECT OF GRAVITATIONAL FORCES

by

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Submitted in partial fulfilment of the requirements
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Department of Chemical Engineering

A mi esposa Nancy

A mi hija Eva

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Certificate of Originality

This is to certify that this work is original, except where specifically acknowledged and was carried out independently by the author in the Department of Chemical Engineering of Loughborough University of Technology.

R.L. Frederick

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Synopsis

An investigation on the effect of gravitational forces on heat transfer in an evaporator tube is reported here. Experiments were carried out with water on a natural circulation, steam heated, 0.872 in. I.D. tube reboiler. Measurements included the circulation rates and axial temperature distribution of the process fluid. The condensation rate of the heating steam in nine independent steam compartments located along the tube was also measured, allowing the determination of local heat transfer coefficients.

The experimental results cover the nucleate and convective regimes of heat transfer in the range of exit qualities from 1.97 to 36.2% and in the range of local heat fluxes from 15200 to 69000 BTU/hr. ft^2. 85 runs on the reboiler gave a total of 765 local data points from which only those in the convective regime at qualities of 2% or more and with liquid and vapour Reynolds number above 2000 were selected for correlation.

The Froude number was proposed as one of the correlating parameters for heat transfer coefficients in two-phase, vertical flow. Three forms of Froude number were considered: based on the homogeneous velocity of the two-phase mixture, on the liquid superficial velocity and on the vapour superficial velocity. The local heat transfer coefficient ratio h_{TP}/h_L was found to decrease with an increase in Froude number at a constant value of the Lockhart-Martinelli parameter. The relevance of the Froude number as a correlating parameter can be associated with the combined effects of gravitational and inertia

forces on the thickness and thermal resistance of the liquid film of the annular flow pattern.

Local heat transfer coefficients were correlated with the Lockhart-Martinelli parameter, the dimensionless film temperature difference and the Froude number in each of its forms. The three equations developed correlate more than 95% of the data points to within ±15%. The equation:

$$\frac{h_{TP}}{h_L} = 7.957 \left(\frac{1}{X_{tt}}\right)^{0.738} \left(\frac{T_b}{\Delta T_f}\right)^{0.06} Fr_g^{-0.194}$$

based on the vapour phase Froude number fitted the data slightly better than the other two. Length-mean heat transfer coefficients at integrated length-mean qualities above 2% were also correlated to within ±15% by the equations developed.

The present data agrees relatively well with the predictions of Dengler-Addoms', Schrock-Grossman's and Abid's correlations. On the other hand the data in reference A1 is not very well correlated by the equations proposed in this work as only the points from the experiments with the lower heat fluxes are within acceptable accuracy limits.

Nomenclature

A:	Total inside heat transfer area	ft^2
A_i:	Inside heat transfer area per compartment	ft^2
A_o:	Inside cross sectional area of the test section	ft^2
Bo:	Boiling number	-
C_p:	Specific heat	BTU/lb^{o}F
D:	Test section diameter	ft
F:	Function	-
Fr:	Homogeneous Froude number	-
Fr_L:	Liquid phase Froude number	-
Fr_g:	Vapour phase Froude number	-
g:	Gravitational acceleration	ft/hr^2
G:	Mass flux	lb/hr ft^2
Ga:	Galileo number	-
h_L:	Liquid phase heat transfer coefficient	BTU/hr ft^2 ^{o}F
h_s:	Condensing steam heat transfer coefficient	BTU/hr ft^2 ^{o}F
h_{TP}:	Two-phase film heat transfer coefficient	BTU/hr ft^2 ^{o}F
H:	Enthalpy	BTU/lb
H_{Lg}:	Latent heat of evaporation	BTU/lb
k:	Thermal conductivity	BTU/hr ft^{o}F
L:	Test section length	ft
ℓ:	Half length of the test section	ft
Nu:	Nusselt number	-
P:	Pressure	psi
Pr:	Prandtl number	-
Q:	Total heat transferred to the test fluid	BTU/hr
Q_i:	Local heat transferred to the test fluid	BTU/hr

q:	Heat flux based on the inside heat transfer area	BTU/hr ft²
Re:	Reynolds number	-
S:	Submergence	%
St:	Stanton number	-
T:	Temperature	^oF
T_{bi}:	Bulk fluid temperature in compartment i	^oF
ΔT_f:	Film temperature difference	^oF
ΔT_{ov}:	Overall temperature difference	^oF
T_s:	Steam temperature	^oC
U:	Overall heat transfer coefficient based on the inside heat transfer area	BTU/hr ft² ^oF
V:	Velocity	ft/sec.
W:	Total mass flow rate	lb/hr
W_L:	Liquid flow rate	lb/hr
W_g:	Vapour flow rate	lb/hr
W_s:	Steam condensate flow rate	lb/hr
x:	Two phase mixture quality	-
x_{bi}:	Quality in compartment i	-
x_{10}	Exit quality	-
X_{tt}:	Lockhart-Martinelli parameter	-
Z:	Axial co-ordinate	ft
δ:	Absolute error	-
μ:	Viscosity	lb/ft hr
ρ:	Density	lb/ft³
σ:	Surface tension	dynes/cm
ϕ:	Two-phase friction multiplier	-

Subscripts

a: Inside (for diameter of the test section)

av: Average

e: Outside (for the diameter of the test section)

f: Film

g: Vapour or gas

i: Compartment number counted from the bottom of the test section ($i=1, \ldots, 9$)

L: Liquid

s: Steam

SAT: Saturation

TP: Two-phase

tt: turbulent-turbulent

1: Tube inlet

10: Tube outlet

Superscripts

$\bar{\ }$: length-mean

': Used in Q', heat flow calculated from the steam condensation rate

Note: Some symbols used less frequently have the meanings given in the text.

1. Introduction

Boiling heat transfer has attracted the interest of many investigators, especially during the last two decades. This interest is motivated by the need to have reliable design data for boiling equipment, particularly at high heat fluxes.

The correlation of two-phase heat transfer coefficients is made difficult by the existence of a number of two-phase flow patterns and heat transfer mechanisms along the length of the evaporator tubes. Accordingly, investigators have tried to correlate local heat transfer coefficients rather than length-mean ones.

The Lockhart-Martinelli parameter has become the most widely used correlating factor for two-phase heat transfer. This parameter was first developed with the aid of experimental data on two-phase flow in horizontal tubes. Therefore, it does not account for the effect of gravitational forces on flow patterns and heat transfer in vertical flow.

An experimental study of heat transfer with water in a natural circulation reboiler is reported here. Experiments in this kind of apparatus usually cover the nucleate and convective regimes of heat transfer particularly in the longer tube evaporators.

Local heat transfer results of this work for the two-phase convective region are used in developing correlations in which provision is made for the effect of gravitational forces.

2. Literature Survey

2.1. Flow patterns and heat transfer mechanisms during evaporation of liquids in tubes

When a gas-liquid mixture flows through a tube, several geometrical configurations (flow patterns) due to a variety of spatial distributions of the two phases can occur. In the particular case of a liquid being evaporated inside a uniformly heated vertical tube, a succession of flow-patterns will appear along the tube, as in Fig. 2.1.

If the temperature of the feed is below the saturation temperature (Section AB), heat will be transferred to the liquid by single phase convection and conduction. Because of the heating, the bulk fluid temperature and the wall temperature will increase up the tube. When the wall temperature equals the saturation temperature at the local pressure, bubbles begin to form at favoured sites on the tube surface. As far as the bulk fluid temperature is still below the saturation temperature, (subcooled boiling, Section BC), the bubbles grow, detach and collapse without reaching the tube axis, and there is no net vapour generation.

When at a certain axial position (C) the bulk of the liquid reaches a saturation temperature, net vapour generation commences. Bubbles form on the surface in increasing numbers and give rise to a disperse phase distributed over the entire cross section (Zone CE, saturated nucleate boiling).

Sections BC and CD constitute the so-called bubbly flow pattern,

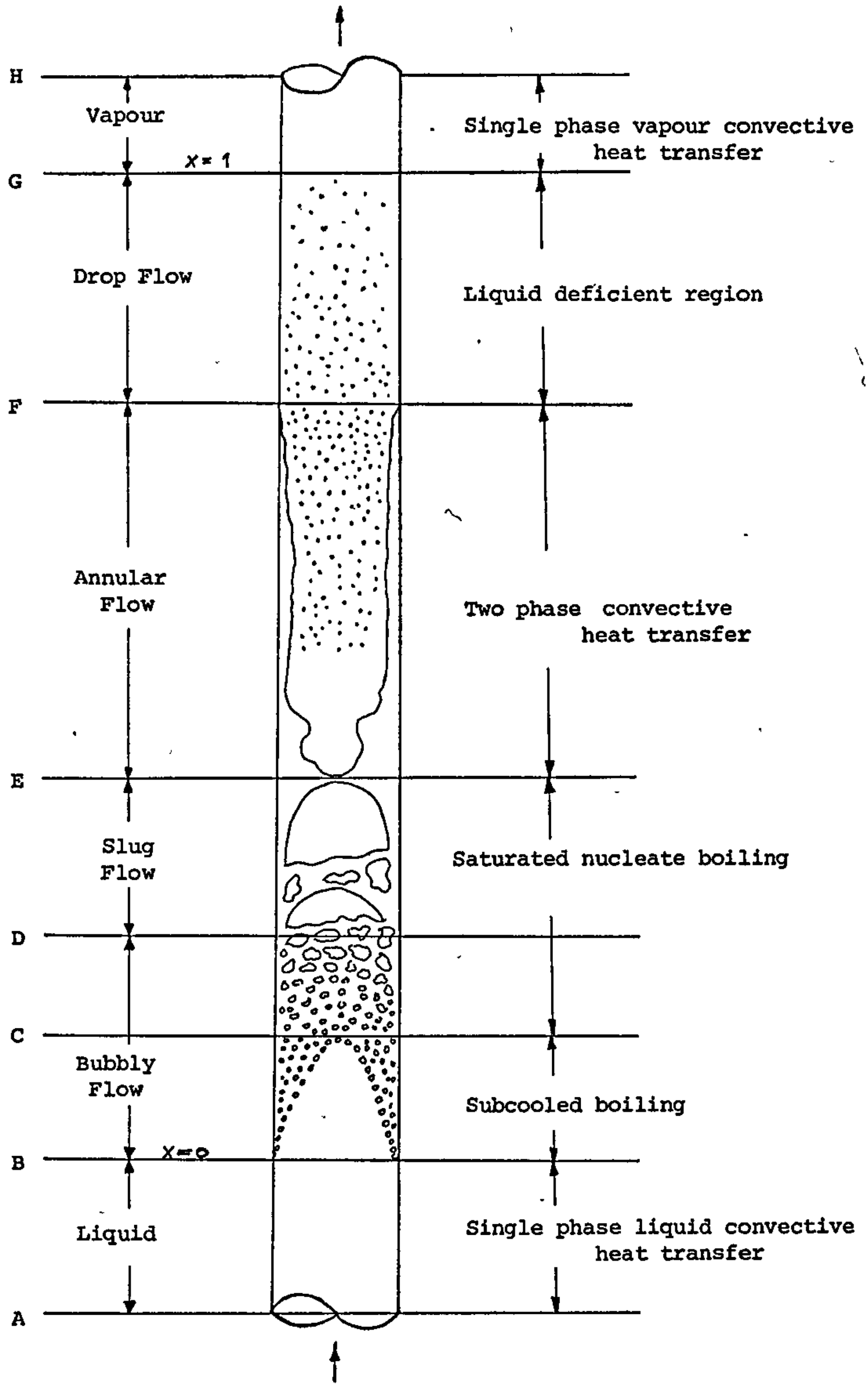


Fig. 2.1. Flow patterns and heat transfer mechanisms during evaporation in a vertical tube.

in which the bubble diameter is much smaller than the tube diameter. The mechanisms of bubble formation in subcooled and saturated nucleate boiling are thought to be essentially the same. The heat transferred in this regime has been found to be independent of flow rate at relatively low velocities (L1, C1). The nucleate boiling regime is restricted to low qualities.

As more and more bubbles are produced, they coalesce to form large bullet-shaped bubbles with diameter of the same order of magnitude as the tube diameter. Liquid fills the spaces between bubbles and a thin liquid film is forced to flow at the wall. This pattern is referred to as slug flow (Section DE).

As evaporation proceeds up the tube, the large bubbles undergo acceleration, causing them to coalesce into a continuous vapour core, while most of the liquid forms a film which covers the wall of the tube. This is the annular flow pattern (Section EF). At the surface of the liquid film, at higher vapour velocities, waves are formed, which are partly sheared off by the fast moving vapour giving rise to the appearance of droplets in the vapour core.

The heat transfer mechanism gradually evolves from nucleate boiling to the <u>two-phase convective region</u>. In the latter, nucleation is suppressed. The liquid in the film remains slightly superheated, the film being thin enough to prevent nucleation even at high heat fluxes. Heat is transferred across the film by convection and conduction, and evaporation takes place at the liquid-vapour interface. The vapour core remains essentially at the saturation temperature.

In the transition from slug to annular regions the convective and nucleate mechanisms of heat transfer are found to coexist. The two-phase convective region is associated mainly with the annular flow pattern, in which the quality may vary between about 2% to about 50%.

Further downstream, where the mixture quality is very high the wall dries out due to complete evaporation of the liquid film. This flow pattern is referred to as drop flow (Section FG) and is characterised by a low heat transfer coefficient, due to the much lower thermal conductivity of the vapour phase which is now in contact with the wall. Evaporation of the liquid from the droplets continues until the quality reaches 100%. In section GH heat is transferred to the vapour by single phase convection.

This succession of flow patterns and heat transfer mechanisms can be found in forced circulation systems as well as in natural circulation ones. In the case of evaporation in a horizontal tube, the influence of gravity modifies the bubbly and slug flow patterns in that bubbles tend to travel in the upper part of the tube. Stratified flow tends to appear and in the annular regime the liquid film is thicker at the lower part of the tube.

The terminology used to describe flow patterns is not uniform. In particular, there is a variety of forms of annular flow which have been given different names by different authors. The transition between slug and annular flow has been termed "churn" or slug-annular flow.

Some authors reserve the term "annular" only for a flow without significant liquid entrainment in the gas core and with a film surface relatively smooth (C4). The annular pattern with liquid entrainment is often called annular mist, drop-annular or slug-annular.

2.2. Correlations of two-phase heat transfer coefficients for single-component liquids

Many correlations proposed for two-phase heat transfer coefficients are based on the Lockhart-Martinelli model for two-phase flow (L2). This model was developed from experimental data of pressure drop and void fraction in horizontal isothermal flow of two-component mixtures. The assumptions of the method excluded bubbly and slug flow from consideration, therefore its application is restricted to annular flow. Although not much attention was given to flow patterns, four flow regimes were distinguished:

a) Turbulent flow of the liquid and gas phases.
b) Viscous flow of the liquid and turbulent flow of the gas.
c) Turbulent flow of the liquid and viscous flow of the gas.
d) Viscous flow of both phases.

The Lockhart-Martinelli parameter, X, was defined as:

$$X = \sqrt{\left(\frac{\Delta P}{\Delta L}\right)_L \Big/ \left(\frac{\Delta P}{\Delta L}\right)_g} \tag{2.1}$$

where $(\Delta P/\Delta L)_L$ and $(\Delta P/\Delta L)_g$ are the liquid and gas pressure drops respectively, assuming each phase to flow alone in the channel.

The two-phase pressure drop was expressed as:

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP} = \phi_L^2 \left(\frac{\Delta P}{\Delta L}\right)_L \tag{2.2}$$

or

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP} = \phi_g^2 \left(\frac{\Delta P}{\Delta L}\right)_g \tag{2.3}$$

It was postulated that ϕ_g, ϕ_L and the liquid and gas volume fractions are functions of X, and this was verified experimentally. In this way, X becomes the governing parameter in the annular type of two phase flow. If both the liquid and the gas phase flow turbulently:

$$X = X_{tt} = \left(\frac{W_L}{W_g}\right)^{0.9} \left(\frac{\rho_g}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_g}\right)^{0.1} \tag{2.4}$$

This condition is attained when the liquid and gas phase Reynolds numbers are above 2000.

The work of Lockhart and Martinelli has been applied to correlating heat transfer coefficients in the two-phase convective region. Correlations of the form:

$$\frac{h_{TP}}{h_L} = A\left(\frac{1}{X_{tt}}\right)^b \tag{2.5}$$

have been used, where h_L represents the liquid phase heat transfer coefficient either for the total stream considered as a liquid or for the unvaporised part of the flow.

One of the earliest local heat transfer studies was made by Dengler and Addoms (D3) in a forced circulation apparatus consisting of a 20 ft., 1 in., I.D. copper tube heated by five independent steam jackets. The test liquid was water. Tube wall temperatures were measured by thermocouples distributed along the tube, and the fluid temperatures were calculated from the saturation curve at the local pressure. A radioactive tracer technique served to estimate liquid and vapour volumetric fractions.

The heat flux q increased along the tube, particularly in the upper portion of it. q increased with the mixture quality, but not with the film temperature difference in this region. It was thought that these characteristics correspond to a convective mechanism of heat transfer. This conclusion was confirmed by the calculation of all-liquid heat fluxes using the correlations for single phase convective heat transfer coefficients at the average mixture velocity (determined from volume fraction measurements). These gave results very similar to the experimental heat fluxes in two phase flow.

In the lower part of the tube, at low qualities, nucleate boiling was the dominant mechanism. In this regime, the heat transfer coefficients were found to increase with the film temperature difference, ΔT_f. If the quality and the total mass flow increased the coefficients became less dependent on the film temperature difference, and at the highest qualities h_{TP} was found to decrease with ΔT_f.

85% of the convective heat transfer coefficients were correlated to within ±20% by their equation of the form:

$$\frac{h_{TP}}{h_L} = 3.5\left(\frac{1}{X_{tt}}\right)^{0.5} \qquad (2.6)$$

where the all-liquid heat transfer coefficients h_L are given by:

$$h_L = 0.023 \frac{k_L}{D} \left(\frac{GD}{\mu_L}\right)^{0.8} \left(\frac{C_p \mu_L}{k_L}\right)^{0.4} \tag{2.7}$$

The authors found that the nucleate and convective contributions to heat flux were additive. However, an empirical correction factor for h_{TP}, designed to account for the suppression of the nucleate contribution by the effect of high liquid velocities was defined.

Guerrieri and Talty (G1) conducted experiments with five organic liquids in an oil-heated, natural circulation vertical tube evaporator. Two test sections, of 0.75 in. I.D. and 1 in. I.D. were used.

Point values of the two-phase heat transfer coefficient in each run increased along the tube from entrance to exit. As the mixture quality, and therefore the velocity of the mixture also increased along the tube, it was suggested that convection was one of the main mechanisms of heat transfer. In addition, at a given quality, the local coefficients of heat transfer and the heat flux increased with an increase in the film temperature difference, suggesting that nucleate boiling also plays a role alongside the convective heat transfer mechanism.

A correlation for the convective region was established as:

$$\frac{h_{TP}}{h_L} = 3.4 \left(\frac{1}{X_{tt}}\right)^{0.45} \tag{2.8}$$

where h_L, the liquid phase heat transfer coefficient was calculated from the Dittus Boelter equation:

$$h_L = 0.023\left(\frac{k_L}{D}\right)\left(\frac{G(1-x)D}{\mu_L}\right)^{0.8}\left(\frac{C_p\mu_L}{k_L}\right)^{0.4} \qquad (2.9)$$

In the determination of the constants of equation 2.8, only the local points at the exit of the test sections were used, as the nucleate contribution was shown to be negligible in that position. The heat transfer coefficients in the nucleate boiling section were bigger than the predictions of equation 2.8. A correction factor in the form of a multiplier called "nucleate boiling correction factor" was designed to be used with equation 2.8, to account for both contributions.

Bennett <u>et al.</u> (B1) conducted experiments with the steam-water system in forced convection at atmospheric pressure in two electrically heated annular test sections, of 0.623 and 0.375 in. O.D. Their results, covering the range of heat fluxes from 31700 to 15800 BTU/hr ft^2, were correlated by the equation:

$$\frac{h_{TP}}{h_L}(q)^{-0.11} = 0.64\left(\frac{1}{X_{tt}}\right)^{0.74} \qquad (2.10)$$

The use of this dimensional equation is intended to account for a slight effect of the heat flux q on the two phase heat transfer coefficients in the convective region of annular flow. h_L was defined in terms of the unvapourised part of the stream. Equation 2.10 was based on local heat transfer data from the 0.623 in. O.D. tube, and correlated them to within ±15%. The results from the 0.375 in. O.D. tube were correlated to within ±20% by the same equation.

Schrock and Grossman (S1) studied heat transfer to water in forced vertical upward flow through electrically heated tubes of 0.1181, 0.237 and 0.4317 in. I.D. Dimensional analysis predicted the following dependence for a two-phase Nusselt number, Nu_{TP}:

$$Nu_{TP} = f(Re, Pr, X_{tt}, Bo) \tag{2.11}$$

where Bo is the "boiling number", defined as:

$$Bo = \frac{q}{G\ H_{Lg}} \tag{2.12}$$

Plots of the ratio $Nu_{TP}/(Re^{0.8}\ Pr^{1/3})$, which is proportional to h_{TP}/h_L, versus X_{tt} with Bo as a parameter showed that at low Bo, the local heat transfer coefficient is a function of X_{tt} alone, while for large values of the boiling number (i.e. for large heat flux to mass flow ratios) the heat transfer becomes independent of X_{tt} and depends only on Bo. The X_{tt}-dependent zone is assumed to contain the annular flow pattern, where the liquid film is thin enough to prevent the occurrence of nucleation. X_{tt} characterises this flow regime.

The results of all the heat transfer experiments were correlated to within ±35% by the equation:

$$\frac{Nu}{Re^{0.8}\ Pr^{1/3}} = 170\left(Bo + 1.5 \times 10^{-4}\ X_{tt}^{-2/3}\right) \tag{2.13}$$

which was recommended for the quality range from 0 to 50%.

Chen (C5) took the experimental data of the previous investigators and compared it with the prediction of each of their correlations. Each equation correlated well the data on which it was based, but none of them correlated the data of others satisfactorily. Chen postulated that the nucleate (microconvective) and macroconvective contributions in the two-phase heat transfer were additive. The macroconvective part was described by the Dittus-Boelter equation in which the physical properties of the two-phase mixture were used instead of those of a single phase:

$$h_{mac} = 0.023\, Re_{TP}^{0.8}\, Pr_{TP}^{0.4} \left(\frac{k_{TP}}{D}\right) \tag{2.14}$$

In an annular flow the heat is transferred to the liquid film, so as an approximation the Prandtl number of the liquid was used:

$$h_{mac} = 0.023\, Re_{TP}^{0.8}\, Pr_{L}^{0.4} \left(\frac{k_{L}}{D}\right) \tag{2.15}$$

The Reynolds number factor, F, defined as follows:

$$F = (Re_{TP}/Re_{L})^{0.8} \tag{2.16}$$

allows one to express Re_{TP} in terms of Re_L. Therefore, equation 2.15 is written as:

$$h_{mac} = 0.023\, Re_{L}^{0.8}\, Pr_{L}^{0.4} \left(\frac{k_{L}}{D}\right) F \tag{2.17}$$

As F is a flow parameter, it was assumed to be a function of X_{tt}. For the microconvective contribution Chen used the Forster and Zuber correlation modified by introducing into it a nucleate boiling suppression factor S. This factor accounts for the suppression of the nucleate mechanism due to flow. The final expression for h_{mic} was:

$$h_{mic} = 0.012 \left[\frac{k_L^{0.79} \, C_{pL}^{0.45} \, \rho_L^{0.49}}{\sigma^{0.5} \, \mu_L^{0.29} \, H_{Lg}^{0.24} \, \rho_g^{0.24}} \right] \Delta T_{SAT}^{0.24} \, \Delta P_{SAT}^{0.75} \, S \qquad (2.18)$$

where $S = (\Delta T_e/\Delta T_{SAT})^{0.24} \, (\Delta P_e/\Delta P_{SAT})^{0.75}$

represents the relationship between the effective wall superheat ΔT_e and the wall superheat ΔT_{SAT}. ΔP_{SAT} and ΔP_e are the vapour pressure differences corresponding to ΔT_{SAT} and ΔT_e respectively. The two-phase heat transfer coefficient is expressed as:

$$h_{TP} = h_{mic} + h_{mac} \qquad (2.19)$$

The Reynolds number factor F and the nucleate boiling suppression factor S were determined from experimental data by means of an iterative procedure. The final correlation, applicable in the quality range from 1 to 70% is in the form of equation 2.17 and 2.18 and as plots of F versus $1/X_{tt}$ and S versus Re_{TP}. The average deviation of the data used was of ±11%.

Collier et al. (C2) modified the correlation of Bennett et al. (B1), equation 2.10, by estimating the physical properties at a film temperature, T_f, defined as:

$$T_f = T_{SAT} + 0.33 \, \Delta T_{SAT} \qquad (2.20)$$

In this way, the effect of heat flux in Bennett's correlation was eliminated. The new expression, based on the same data as equation 2.10 was:

$$\frac{h_{TP}}{h_L} = 2.719 \left(\frac{1}{X_{tt}}\right)^{0.65} \tag{2.21}$$

with a standard deviation of 11.5%. New data obtained in the same apparatus as in reference B1 was presented. An equation based on the whole data (over 1500 local data points) is:

$$\frac{h_{TP}}{h_L} = 2.167 \left(\frac{1}{X_{tt}}\right)^{0.699} \tag{2.22}$$

with a standard deviation of 26.9%. After analysing Schrock and Grossman's correlation, the authors concluded that any correlation in which the convective and nucleate contributions are added is unlikely to represent data accurately in both regions, due to the entirely different nature of both heat transfer mechanisms.

Davis and David (D2) proposed a correlation in which the Martinelli parameter did not appear. A simple model was formulated for annular and annular mist flow. An equation similar to the Dittus-Boelter equation was assumed to represent two-phase heat transfer coefficients:

$$\frac{h_{TP}\, D}{k_L} = B\left(\frac{D\, \rho_L\, \bar{u}_L}{\mu_L}\right)^a \left(\frac{C_p\, \mu_L}{k_L}\right)^b \tag{2.23}$$

where $\bar{u}_L$ is the average superficial liquid velocity. This equation is rearranged by expressing $\rho_L\, \bar{u}_L$ in terms of the slip ratio α, the total mass velocity and quality.

$$\frac{h_{TP} D}{k_L} = \frac{B}{\alpha^a} \left(\frac{D\, G\, x}{\mu_L}\, \frac{\rho_L}{\rho_g}\right)^a \left(\frac{C_p\, \mu_L}{k_L}\right)^b \tag{2.24}$$

α was assumed to be a function of the vapour and liquid flow rates, the geometrical and physical properties and the flow pattern. The authors determined B/α^a as a function of the liquid-vapour density ratio:

$$\frac{B}{\alpha^a} = B' \left(\frac{\rho_L}{\rho_g}\right)^{-0.59} \tag{2.25}$$

Finally:

$$\frac{h_{TP}\,D}{k_L} = 0.06 \left(\frac{\rho_L}{\rho_g}\right)^{0.28} \left(\frac{D\ G\ x}{\mu_L}\right)^{0.87} \left(\frac{Cp\ \mu_L}{k_L}\right)^{0.4} \tag{2.26}$$

This equation correlated data of several investigations to within an average error of 17% for vapour qualities above 10%.

Wright <u>et al</u>. (W2) experimented with water and n-butanol in forced vertical downflow electrically heated tubes. The range of heat flux was between 13800 and 88000 BTU/hr ft². The experimental data was plotted together with the predictions of Dengler's (D3) and Schrock and Grossman's (S1) correlations. As considerable differences were found, the authors proposed two correlations in terms of the four significant parameters used also by Schrock and Grossman. These equations are:

$$St = 0.9005\ Re_L^{+0.286}\ X_{tt}^{-0.292}\ Bo^{0.191}\ Pr_L^{-0.233} \tag{2.27}$$

$$Nu = 0.9273\ Re_L^{-0.717}\ X_{tt}^{-0.345}\ Bo^{0.194}\ Pr_L^{0.800} \tag{2.28}$$

These correlations were obtained from data in the quality range from 0 to 17% for water and from 0 to 31% for n-butanol. The authors thought that most of the data belonged to the convective region. Correlation

2.27 was found to represent the authors' data to within ±15%, and the data of Schrock and Grossman (S1) and Bennett (B1) to within ±30%. Equation 2.28 was not as successful when compared with data of these authors.

Pujol and Stenning (P1) conducted experiments on heat transfer to Freon 113 in an apparatus consisting of tubes arranged for up and down-flow. In agreement with previous investigations (S1, W2) they found that the heat transfer coefficients can be expressed in terms of Re, Pr, X_{tt} and Bo. The existence of the convective and nucleate regimes, in both upward and downward flow was observed. In the nucleate regime the upflow coefficients were higher than the downflow ones. Nucleation was suppressed at higher values of X_{tt} in downflow than in upflow at the same boiling number. In the nucleation-suppressed region both the upflow and the downflow heat transfer coefficients were essentially equal. The following correlation was proposed for the convective region:

$$\frac{h_{TP}}{h_L} = 4.0 \left(\frac{1}{X_{tt}}\right)^{0.37} \tag{2.29}$$

which correlated the authors' data to within ±15%. In the nucleate regime and in the mixed nucleate-convective regime the direction of flow determines the value of h_{TP}. For this reason, alternative forms of correlation were proposed. For upflow:

$$\frac{h_{TP}}{h_L} = 0.9 \left[Bo \times 10^4 + 4.45 \left(\frac{1}{X_{tt}}\right)^{0.37} \right] \tag{2.30}$$

and for downflow:

$$\frac{h_{TP}}{h_L} = 0.53 \left[Bo \times 10^4 + 7.55 \left(\frac{1}{X_{tt}}\right)^{0.37} \right] \qquad (2.31)$$

These equations are not as accurate in the convective region as equation 2.29, but they correlate the data in the nucleate boiling region better than equation 2.29.

Calus et al. (C6) conducted experiments on a steam-heated thermosiphon reboiler using 3 test sections of 0.5 in. nominal diameter, one of which had the steam jacket divided into 6 independent compartments for the determination of local heat transfer coefficients. Five test liquids were used.

After analysing previous work in the field the authors conclude that the failure of attempts to correlate heat transfer coefficients in the nucleate and convective regimes may be due to the fact that some variables, like the film temperature difference ΔT_f and the surface tension σ were not considered. In natural circulation reboilers the quality of the mixture, heat flux and the liquid and vapour flow rates depend on ΔT_f. It was experimentally found that the ratio h_{TP}/h_L increases with ΔT_f at constant submergence. A plot of h_{TP}/h_L versus $1/X_{tt}$ showed that points with approximately the same ΔT_f tend to group themselves into a straight line. Accordingly, the length-mean water data were correlated to within ±20% by the equation:

$$\frac{h_{TP}}{h_L} = 0.065 \left(\frac{1}{X_{tt}}\right)\left(\frac{T_{SAT}}{\Delta T_f}\right) \qquad (2.32)$$

The saturation temperature was introduced in order to non-dimensionalise ΔT_f and to facilitate the use of the correlation with liquids of different boiling points.

The surface tension of a liquid, σ_L, is important because it determines the size of bubbles in the nucleation process. It is therefore a strong correlating parameter in flow boiling where the nucleate boiling mechanism is present alongside the convective process. The heat transfer coefficients for liquids other than water were correlated by:

$$\frac{h_{TP}}{h_L} = 0.065 \left(\frac{1}{X_{tt}}\right)\left(\frac{T_{SAT}}{\Delta T_f}\right)\left(\frac{\sigma_{H2O}}{\sigma_L}\right)^{0.9} \qquad (2.33)$$

with an accuracy of ±20%. Local heat transfer coefficients were correlated to within ±30% by equation 2.33, except the points derived from a dry wall condition.

2.3. The effect of gravitational forces on two-phase heat transfer

In single phase flow in closed ducts the Reynolds number (relationship between inertia and viscous forces) is a sufficient parameter for the description of the flow regime. In a two-phase flow, the appearance of a second phase gives rise to interfacial forces and the area available for the flow of each phase is reduced. Gravity and surface tension forces become important in determining the flow pattern.

It is generally assumed that gravity is an important force in liquid flows with a free surface, where waves are formed by the interaction of gravity and inertia forces. In gaseous systems the effect of gravity is negligible except when large density differences due to temperature gradients give rise to natural convection (J1, I1). The Froude number is often used as a similarity criterion in the former type of system.

Very few research works on the effect of gravitational forces on the process of boiling heat transfer are available. However, their effect on two-phase flow patterns has received wider attention. Gravity is considered to be the principal factor in the determination of the rise velocity of bubbles in slug flow (G1, Q1).

A number of aspects of the fluid mechanics of two phase flow has been covered by specialised work in references C4, A2, C3. Detailed reviews of these problems may be found in the books by Collier (C1) "Convective boiling and condensation", and by Hewitt and Hall-Taylor (H1) "Annular two phase flow".

Some research workers noticed that the difficulties of correlating boiling data with the Lockhart-Martinelli parameter might be due to the fact that this parameter was developed with the help of experimental data from horizontal tubes. This problem was analysed by Davis (D1). He studied pressure drop data of Govier et al. (G3) for vertical flow of air-water mixtures and of Isbin et al. (I2) for steam-water mixtures. The frictional pressure drop was calculated by subtracting the hydrostatic head and acceleration components from the total pressure drop.

The results were plotted as $\phi_L = (\Delta P_{TP}/\Delta P_L)^{\frac{1}{2}}$ versus the Lockhart-Martinelli parameter, X_{tt}. The experimental values of ϕ_L were higher than the ones predicted by the Lockhart-Martinelli correlation. As this was obtained from data in horizontal two-phase flow, it was concluded that frictional two-phase pressure losses for vertical flow were higher than for horizontal flow.

Davis modified the Lockhart-Martinelli parameter by including a homogeneous Froude number. This correction put all the experimental data on a single line with all the data within the ±10% accuracy lines. The modified parameter is:

$$X'_{tt} = 0.19 \left(\frac{W_L}{W_g}\right)^{0.9} \left(\frac{\rho_g}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_g}\right)^{0.1} \left(\frac{V_m^{\,2}}{gD}\right)^{0.125} \qquad (2.34)$$

Where V_m is the homogeneous velocity of the two-phase mixture. Davis concluded that an error of ±10% in ϕ_L implies that the error in pressure drop would be about ±20%. At the highest velocities the unmodified correlation fitted the vertical data very well. This was attributed to the existence of a thinner film where gravitational forces are less important. The revised correlation was valid for the turbulent-turbulent regime at liquid Reynolds numbers above 8000 and gas Reynolds numbers above 2100.

Chawla (C7) considers that previous heat transfer correlations have failed because they do not include all the pertinent variables, such as the acceleration of gravity.

The liquid and vapour phases flow at different velocities through a tube. The resulting exchange of momentum between the phases influences the pressure drop. A two-phase flow parameter, ε, defined as the ratio of the mean liquid velocity to the mean vapour velocity is proposed to account for this effect. ε is correlated empirically in a graph as a function of the product.

$$\frac{1-x}{x}\left(Re_L\ Fr_L\right)^{-1/6}\left(\frac{\rho_L}{\rho_g}\right)^{-0.9}\left(\frac{\mu_L}{\mu_g}\right)^{-0.5}$$

where:

$$Re_L = \frac{G(1-x)D}{\mu_L}, \quad \text{liquid Reynolds number}$$

$$Fr_L = \frac{[G(1-x)]^2}{\rho_L^{\,2}\ gD}, \quad \text{liquid Froude number}$$

In correlating heat transfer coefficients it was assumed that most of the heat is transferred from the tube wall through a liquid film. The hydraulic diameter of the film, D_L is expressed as a function of the parameter ε.

$$D_L = D\left[1-\left(1+\frac{1-x}{x\varepsilon\left(\frac{\rho_L}{\rho_g}\right)}\right)^{-\frac{1}{2}}\right]$$

A Nusselt number is defined in terms of D_L:

$$Nu_L = \frac{h_{TP}\ D_L}{k_L} = \frac{h_{TP}\ D}{k_L}\left[1-\left(1+\frac{1-x}{x\varepsilon\left(\frac{\rho_L}{\rho_g}\right)}\right)^{-\frac{1}{2}}\right] \qquad (2.35)$$

The following equations were proposed for Nu_L:

a) For $Re_L\ Fr_L < 109$

$$Nu_L = 0.0066 \left(Re_L\ Fr_L\right)^{0.475} \left(\frac{x}{1-x}\right)\left(\frac{\rho_L}{\rho_g}\right)^{0.3} \left(\frac{\mu_L}{\mu_g}\right)^{0.8} Re_L^{\ 0.35}\ Pr_L^{\ 0.42} \tag{2.36}$$

b) For $Re_L\ Fr_L > 109$

$$Nu_L = 0.015 \left(Re_L\ Fr_L\right)^{0.3} \left(\frac{x}{1-x}\right)\left(\frac{\rho_L}{\rho_g}\right)^{0.3} \left(\frac{\mu_L}{\mu_g}\right)^{0.8} Re_L^{\ 0.35}\ Pr_L^{\ 0.42} \tag{2.37}$$

The heat transfer data used to determine the various constants in Chawla's equations were derived from heat transfer experiments with single-component liquids in horizontal and vertical flow. The correlation predicted heat transfer coefficients with an accuracy of ±30% over a wide quality range.

Abid (A1) investigated the effect of geometry on the heat transfer in natural circulation reboilers, using two test sections of 0.5 and 1 in. nominal diamter. It was found that the heat transfer coefficients are higher for larger diameter tubes, due to an earlier attainment of the annular flow pattern which is more favourable to heat transfer. An increase in diameter also increases mass velocity, resulting in a more stable operation.

The effect of gravitational acceleration was considered to be important in vertical flow, as the interaction of gravity and viscous forces affects the flow rate. The Galileo number, Ga, was found to be a measure of the combined effects of these forces.

$$Ga = Re \frac{\text{(Gravitational force)}}{\text{(Viscous force)}}$$

$$Ga = \frac{D^3 g \rho^2}{\mu^2}$$

In addition, the Galileo number provides a convenient dimensionless quantity accounting for the effect of diameter. Over 80% of the local water data from the two test sections in the quality range from 2% to 60% was correlated to ±30% by the equation:

$$\frac{h_{TP}}{h_L} = 0.043 \left[Ga^{0.3}\left(\frac{1}{X_{tt}}\right)\right]^{0.7} \tag{2.38}$$

As the data from the bottom and top of the tube showed the biggest deviations from the correlating line, the empirical correction factor $(\ell/Z)^{0.3}$ was applied to equation 2.38 to account for the effect of the position in the tube. Equation 2.38 becomes:

$$\frac{h_{TP}}{h_L} = 0.043 \left[Ga^{0.3}\left(\frac{1}{X_{tt}}\right)\left(\frac{\ell}{Z}\right)^{0.3}\right]^{0.7} \tag{2.39}$$

where ℓ is half the length of the tube and Z is the distance from the tube inlet to the centre of each compartment. The use of this factor improves the scatter of the data points, as 85% of them are correlated to ±30% by equation 2.39.

3. Experimental Work

3.1. Apparatus

The experimental work was carried out on a steam-heated, natural circulation single tube evaporator, using distilled water as a test liquid. Fig. 3.1. shows a flow diagram of the apparatus. Table 3.1. contains the dimensions of the evaporator tube. Table 3.2. shows dimensions and materials of construction of the equipment. The apparatus described here was used in previous research work (A1).

The test liquid, at or near the saturation temperature from a steam-coil preheater (1), passes to a 1 in. dia. vertical stainless steel test section (2), where part of the feed is evaporated. The test section (2) is heated by means of steam jackets located along its length. A liquid/vapour separator head (3) divides the two-phase mixture at the exit of the tube into two streams (4,5). Entrained liquid is removed from the vapour stream (4) in two spherical QVF glass cyclones connected in series (6,7). Condensation of the vapour takes place in a water-cooled copper condenser (8) and the condensate goes to a submerged orifice flowmeter (9) and then to a calibrated flask (10) from which samples of condensate can be taken. From the flask, the condensate passes to a constant-level tank (11).

The liquid streams from the two cyclone separators (6,7) and from the vapour/liquid separator (3) are led to the second orifice flowmeter (12) from which they pass to the constant level tank (11). The level of liquid in (11) is kept constant by means of the ball valve (28).

Liquid from this tank (11) is pumped by means of a STUART No. 12 centrifugal pump (14) to the glass capacity vessel (15) which is mounted on the preheater (1).

The capacity vessel, the preheater and the test section form a U-tube system. The height of liquid in the capacity vessel balances a column of boiling two-phase fluid inside the test section, and provides the necessary driving force for maintaining a vertical ascending two-phase flow through it. This height is referred to as <u>submergence</u> in this type of system.

The evaporator tube (2) consists of nine equal compartments joined together by means of flanges. Each compartment has a steam jacket, made from 3 in. dia. stainless steel tube. Each jacket is fed with steam and drained independently.

Steam supplied by a STONE gas-fired boiler at 150 psig is first reduced to the desired pressure by a Bailey reducing valve in the steam line, and then fed to the steam jackets where the steam condenses, transferring its latent heat to the evaporating fluid. The condensate leaving each jacket is led to a SPIRAX steam trap (19 to 27) whose output can be collected and measured. The lower part of each steam jacket has a concentric baffle separating the condensates formed on the outer wall of the test section and on the inner wall of the 3 in. tube forming the jacket. Both condensate streams are led to different steam traps. The details of the construction of individual steam jackets are shown in Figs. 3.2 and 3.3.

Table 3.1.

Dimensions of the Evaporator Tube

Inside diameter	0.07266 ft.
Outside diameter	0.08343 ft.
Total heated length	6.09 ft.
Total length including all flanges except top and bottom ones	6.736 ft.
Total outside heated area	1.6 ft.^{2}
Total inside heated area	1.39 ft.^{2}
Inside cross sectional area	0.004146 ft.^{2}
Heated length per compartment	0.6766 ft.
Outside heated area per compartment	0.1777 ft.^{2}
Inside heated area per compartment	0.1544 ft.^{2}

The ball valve (28) is designed to maintain a constant level of liquid in the capacity vessel (15) and in the tank (11). If during operation, the pump takes more liquid than the sum of condensate and circulating liquid flows, the excess is returned to the constant level tank through the ball valve. This arrangement has proved efficient in maintaining constant submergence at a given steam temperature and given quantity of liquid contained in the loop.

The pressure in the apparatus is kept essentially at atmospheric level by means of vents located at the top of the capacity vessel, the constant level tank, all the condensers and the submerged liquid orifice flowmeter. In addition, these vents serve to eliminate non-condensable gases, initially dissolved in the test liquid. All steam jackets are vented as well.

Flow measurement

The calibrated flask (10) is used to measure the vapour condensate flow rate. A 3-way valve at the bottom of the flask allows timed samples of condensate to be taken.

The submerged orifice flowmeter (12) was not used. Instead, its liquid output is diverted by means of an AUDCO valve, to a calibrated 3 in. dia. glass cylinder (13) in which the circulation rate is determined by noting the time taken by the liquid to fill a specified volume.

Temperature measurement

Ten chromel/alumel thermocouples installed through $\frac{1}{8}$ in. dia. holes in the bottom flange of each compartment are used to measure the bulk fluid temperature at the inlet and outlet of every compartment, giving the temperature profile along the evaporator tube. The reference junctions for the thermocouples are installed in an AEI thermostatic vessel. The cold junction temperature is kept at about $44^{O}C$ by the thermostat. A thermometer inserted in the thermostatic vessel records its actual temperature. The thermocouple circuits are connected with a Dynamco Systems digital voltmeter. Thermocouple readings can be recorded either on a DM 200 typewriter or on a Data Dynamics 1110 paper punch unit, both connected to the voltmeter.

A mercury in glass thermometer (29) inserted in a thermometer well located 5.5 cm below the flange of the bottom section of the evaporator measures the inlet fluid temperature. A second thermometer (30) in the vapour separator head (3) is used to check the outlet temperature. The heating steam temperature before it enters the steam jackets is measured by a mercury thermometer installed in a mercury-filled thermometer pocket (18). All these thermometers were calibrated against an NPL-tested thermometer, whose characteristics can be found in Appendix II.

Pressure measurement

A U-tube mercury manometer (31) measures the static pressure at the bottom of the test section. The second manometer (32) measures the pressure in the separator head. The atmospheric pressure is measured by a Casella mercury barometer installed in the Laboratory.

3.2. Experimental procedure

At the beginning of a run, first cooling water was turned on to all the condensers, then the steam was switched on to the preheater (1) and then to the test section itself (2). This step was taken in the following manner: The drain valves were kept open until steam alone appeared through the drains. This was necessary in order to eliminate any dirt contained in the narrow passages of the preheater and the test section.

Table 3.2.

Characteristics of the Equipment in Fig. 3.1.

No. in Fig.3.1.	Description	Length or Height	Diameter	Material
1	Preheater	24 in.	9 in.	Steel
2	Test section	6 ft.	1 in.	Stainless Steel
3	Liquid/vapour separator	15 in.	3 in.	QVF glass
4,5	Vapour and liquid lines from (3)	-	1 in.	QVF glass
6,7	Cyclone separators	-	14.6 in.	QVF glass
8	Condenser	54 in (tubes)	$\frac{19}{32}$ in.	Copper
9	Submerged orifice flowmeter for vapour condensate	2 ft.	3 in.	QVF glass
10	Calibrated flask	-	3 in.	QVF glass
11	Constant level tank	2 ft.	1 ft.	Stainless Steel
12	Submerged orifice flowmeter for circulating liquid	2 ft.	4 in.	QVF glass
13	Calibrated measuring cylinder	-	3 in.	QVF glass
14	Centrifugal pump	-	-	Steel
15	Capacity vessel	8 ft.	4 in.	QVF glass
16,17	Bourdon pressure gauges	-	-	-
18,28,29	Mercury thermometers	-	-	-
19 to 27	Steam traps	-	-	Steel
31	Mercury manometer	-	-	-
32	Water manometer	-	-	-

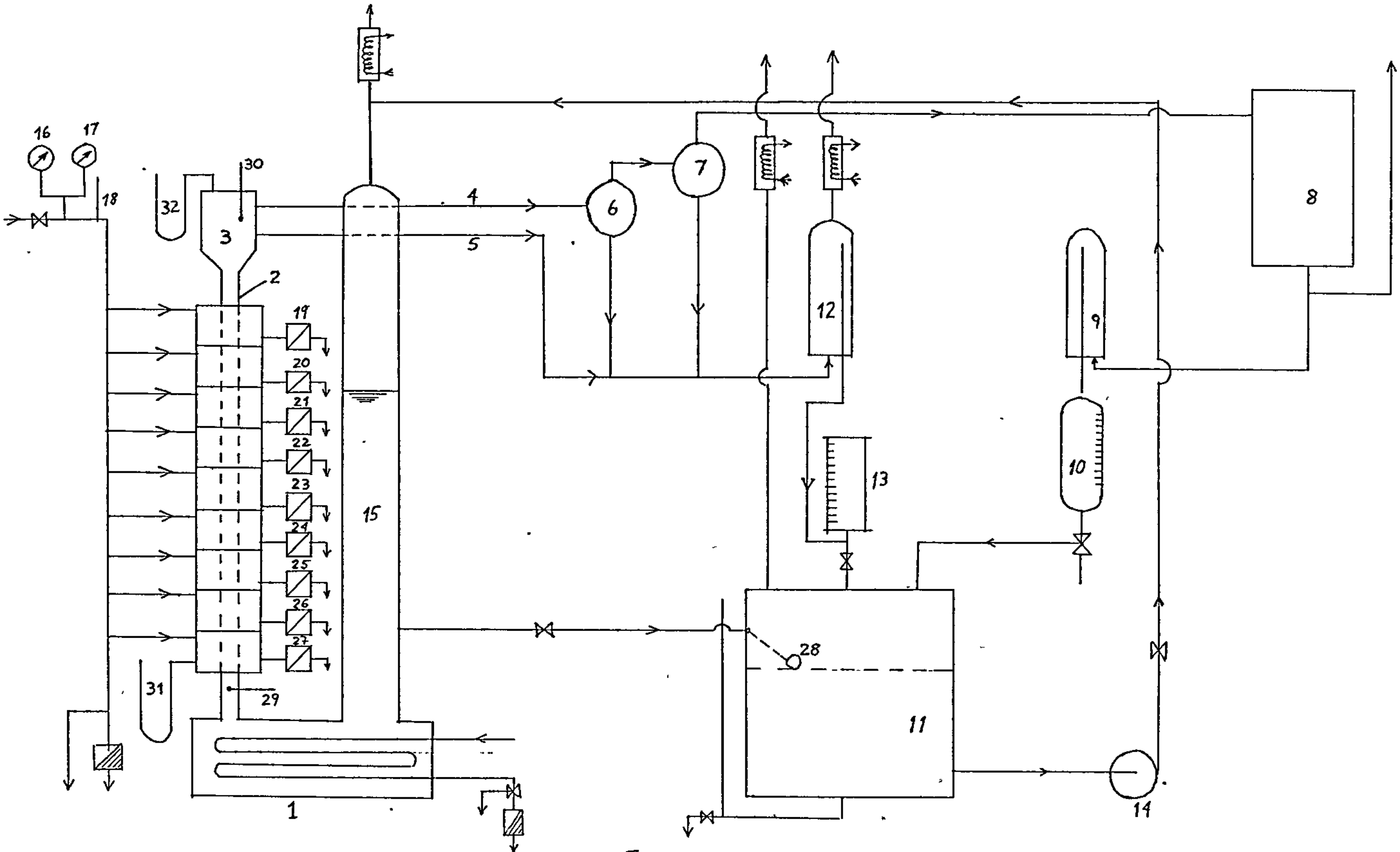


Fig 3.1 Flow Diagram of the Apparatus

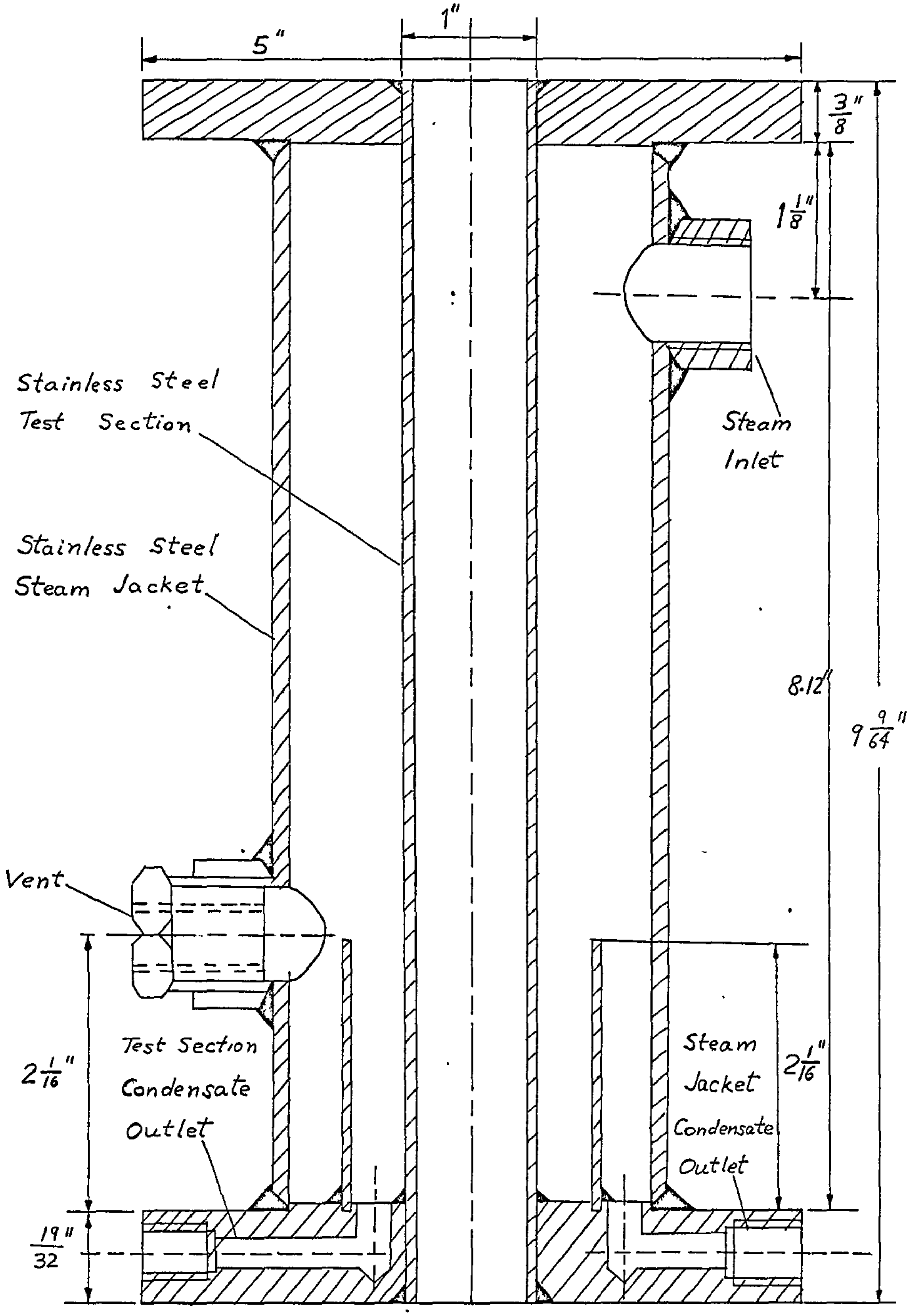
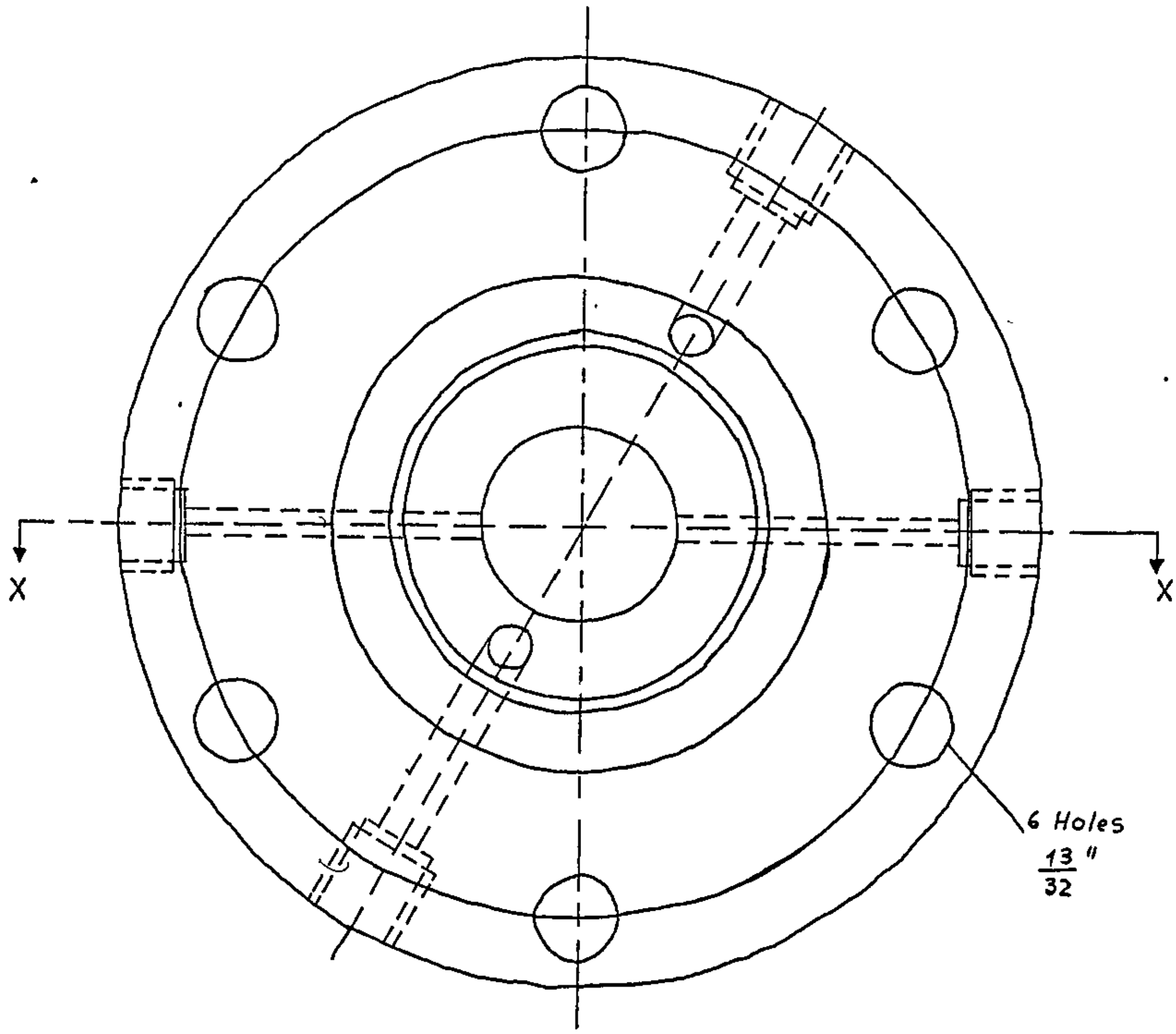
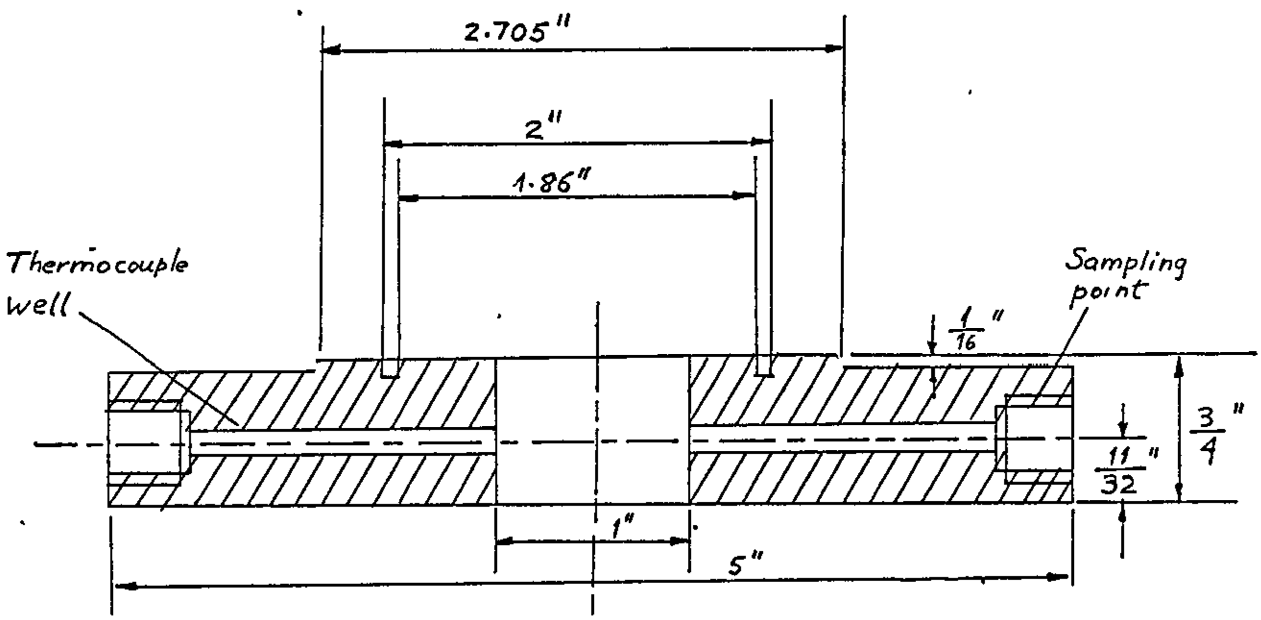


Fig. 3.2. Standard Compartment of the Test Section





Section through XX

Fig. 3.3. Bottom standard flange showing the location of the thermocouple well and sampling point

The pressure and temperature of the steam were controlled by means of the reducing valve. A sight glass at the base of the test section allowed visual observation of the boiling process. In the work reported here, the submergence was controlled either by adding some liquid or withdrawing it from the constant level tank (11). The system was given two hours to reach steady state conditions, which were indicated by the steadiness of repeated readings of the ten thermocouples.

Nine two-litre beakers were used to collect timed samples of steam condensate simultaneously from the nine steam traps. Steam pressure and temperature were noted during the period of condensate collection. Due to randomness of discharge of the condensate from steam traps a smoothing procedure was applied as explained on page 197. This approach was adopted in preference to a potentially over-rigorous screening procedure.

Ten temperature readings were taken from each thermocouple. Next the temperature at the inlet and outlet of the test section, indicated by mercury thermometers, were noted. This was followed by taking note of the pressure indicated by manometers located at the same points. The height of liquid in the capacity vessel was measured.

Flow measurements of the process condensate and of the circulating liquid were made last because of the interference with the steady state conditions they produced. A timed sample was taken from the flask (10), in order to determine the vapour condensate flow rate. Then the circulating liquid flow rate was measured by the procedure explained in 3.1. Approximately 15 minutes after returning the samples to the constant level tank (11), duplicate readings could be obtained. Finally the atmospheric pressure was noted. The volume of the steam condensate samples was measured with a glass measuring cylinder of 1-litre capacity and their temperature was noted at the time the volume measurements were made.

When shutting down, the steam supply to the preheater and the steam jackets was stopped and the drain valves were opened to drain all the steam lines. Then the circulating liquid pump was turned off and the cooling water supply was stopped. When two consecutive runs were to be made without shutting down, some liquid was added to or removed from the constant level tank and the system was given an hour to settle. This period of time was considered enough, as the system was already warmed up.

3.3. Data treatment

The calculation procedures used in processing experimental data are outlined here. Detailed sample calculations are presented in Appendix III.

3.3.1. Primary variables

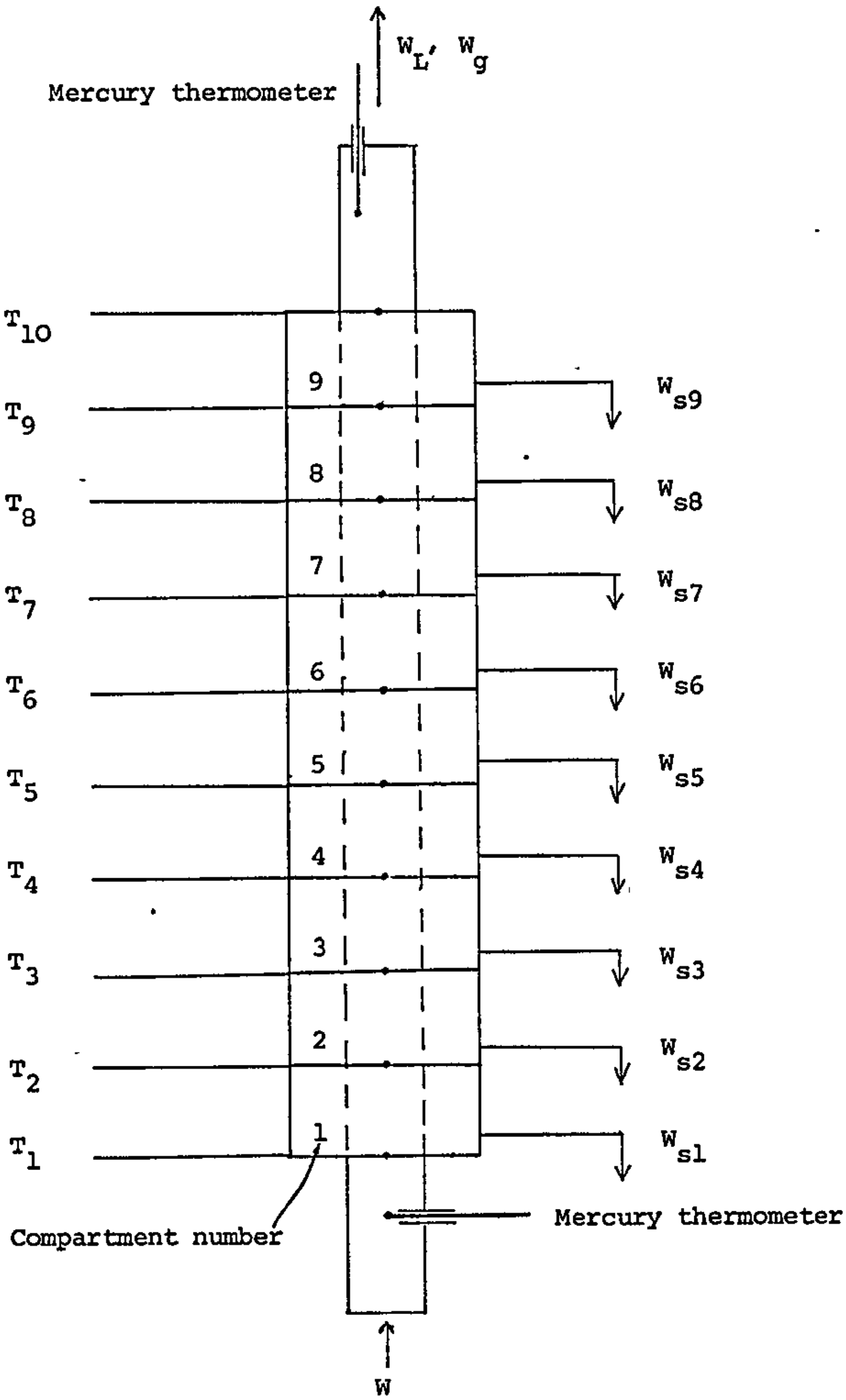


Fig. 3.4. The position of the thermocouples (T_1 to T_{10}), of the mercury thermometers and of the condensate sampling points.

The following variables are determined directly:

W_L: circulating liquid flow rate at the tube exit.

W_g: vapour condensate flow rate at the tube exit.

T_s: steam temperature.

T_i: bulk fluid temperature at the inlet and outlet of each compartment (i = 1, ..., 10).

W_{si}: steam condensate flow rate from each of the nine steam compartments (i = 1, ..., 9).

3.3.2. Total heat transferred to the evaporating fluid, Q.

A heat balance for the whole length of the tube (Fig. 3.4.) is:

$$Q + W\,H_{L1} = W_L\,H_{L10} + W_g\,H_{g10} \tag{3.1}$$

where H_{L1} is the enthalpy of liquid at the inlet, H_{L10} is the enthalpy of liquid at the outlet, and H_{g10} represents the vapour enthalpy at the exit of the test section. From the mass balance:

$$W = W_L + W_g \tag{3.2}$$

Eliminating W_L between (3.1) and (3.2)

$$Q = W_g(H_{g10} - H_{L10}) + W(H_{L10} - H_{L1}) \tag{3.3}$$

where $H_{g10} - H_{L10}$ is the latent heat of evaporation of the fluid at the exit conditions.

3.3.3. Local heat transfer coefficients and related quantities

Mean temperature of the bulk fluid in each compartment, T_{bi}

$$T_{bi} = \frac{T_i + T_{i+1}}{2} \qquad (i = 1, \ldots, 9) \tag{3.4}$$

Overall temperature driving force in each compartment, ΔT_{ovi}

$$\Delta T_{ovi} = T_s - T_{bi} \qquad (i = 1, \ldots, 9) \tag{3.5}$$

Heat transferred to each of the nine compartments of the evaporator tube, Q_i

From the steam condensate flow rate measurements, a first approximation to Q_i can be calculated. This first approximation is denoted Q_i'.

$$Q_i' = W_{si} H_{Lg} \qquad (i = 1, \ldots, 9) \tag{3.6}$$

where W_{si} is the condensation rate in each steam jacket and H_{Lg} is the latent heat at the steam temperature. The sum of the nine values of Q_i' will be bigger than Q, due to heat losses to the surroundings.

$$Q' = \sum_{i=1}^{9} Q_i' > Q \tag{3.7}$$

Corrected values of heat flow to each section are obtained by applying a correction factor to Q_i'.

$$Q_i = Q_i' \frac{Q}{Q'} \qquad (i = 1, \ldots, 9) \tag{3.8}$$

Local heat flux, q_i

$$q_i = Q_i/A_i \qquad (i = 1, \ldots, 9) \tag{3.9}$$

where A_i is the inside heat transfer area of each section.

Local overall heat transfer coefficients, U_i

$$U_i = q_i/(\Delta T_{ovi}) \qquad (i = 1, \ldots, 9) \qquad (3.10)$$

Local two phase heat transfer coefficients, h_{TPi}

The reciprocal of the overall heat transfer coefficient is the sum of three thermal resistances, namely, the resistance on the evaporating side, the conduction resistance of the tube wall, and the condensing steam resistance.

$$\frac{1}{U_i} = \frac{1}{h_{TPi}} + \frac{D_a \ln (D_e/D_a)}{k_{si}} + \frac{D_a}{h_{si}\, D_e}$$

where D_a and D_e are the inside and outside diameters of the test section, respectively. Therefore:

$$h_{TPi} = \frac{1}{\frac{1}{U_i} - \frac{D_a \ln (D_e/D_a)}{k_{si}} - \frac{D_a}{h_{si}\, D_e}} \qquad (3.11)$$

The condensing steam heat transfer coefficient h_{si} is calculated from an empirical equation developed by B.A. Abid (A1) on the same apparatus.

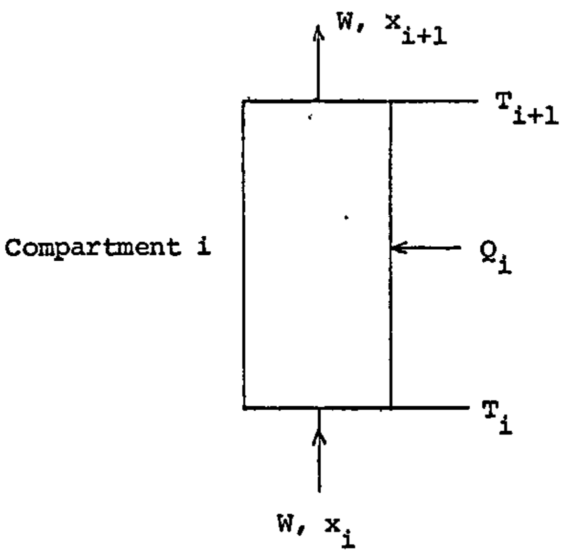
$$h_{si} = 3826 - 0.01\, q_i \qquad \frac{\text{BTU}}{\text{hr ft}^2\,{}^\circ\text{F}} \qquad (3.11a)$$

where q_i is in [BTU/(hr ft²)]. The thermal conductivity of the material at the mean wall temperature is given by:

$$k_{si} = 9.15 + 0.0066\, \frac{T_s + T_{bi}}{2} \qquad \frac{\text{BTU}}{\text{hr ft}\,{}^\circ\text{F}} \qquad (3.11b)$$

The quality of the two-phase mixture in the individual compartments

Having determined the quality of the exit mixture, x_{10}, and the heat added to each of the compartments, Q_i, the quality in the remaining compartments can be calculated by means of heat balances written over each of them.



$$Q_i + W(1-x_i)H_{Li} + Wx_iH_{gi} =$$

$$= W(1-x_{i+1})H_{L\,i+1} + W\,x_{i+1}\,H_{g\,i+1}$$

Rearranging:

$$x_i = \frac{x_{i+1}\,H_{Lg\,i+1} + H_{L\,i+1} - H_{Li} - (Q_i/W)}{H_{Lgi}} \tag{3.12}$$

where $H_{Lgi} = H_{gi} - H_{Li}$

$$H_{Lg\,i+1} = H_{g\,i+1} - H_{L\,i+1}$$

Since the inlet and outlet temperatures in each compartment are known, the latent heats and liquid enthalpies are also known. Equation (3.12) can be used as a recurrence formula. Starting with:

$i = 9, \quad x_{i+1} = x_{10}$ (exit quality)

$$x_9 = \frac{x_{10} H_{Lg10} + H_{L10} - H_{L9} - (Q_9/W)}{H_{Lg9}}$$

with the value of x_9 known from this calculation, the value of x_8 can be calculated from equation (3.12) and so on.

The mean quality in each section, x_{bi} is given by:

$$x_{bi} = \frac{x_i + x_{i+1}}{2} \qquad (i = 1, \ldots, 9) \qquad (3.13)$$

<u>Lockhart-Martinelli parameter, $(^1/X_{tt})_i$</u>

$$\left(\frac{1}{X_{tt}}\right)_i = \left(\frac{x_{bi}}{1 - x_{bi}}\right)^{0.9} \left(\frac{\rho_{Li}}{\rho_{gi}}\right)^{0.5} \left(\frac{\mu_{gi}}{\mu_{Li}}\right)^{0.1} \qquad (3.14)$$

in which all properties are calculated at the mean temperature of the section, T_{bi}.

<u>Local film temperature difference, ΔT_{fi}</u>

$$\Delta T_{fi} = \frac{q_i}{h_{TPi}} \qquad (i = 1, \ldots, 9) \qquad (3.15)$$

<u>Dimensionless reciprocal of the film temperature difference</u>

It is calculated by evaluating the expression:

$$T_{bi}/\Delta T_{fi} \qquad (i = 1, \ldots, 9) \qquad (3.16)$$

in which T_{bi} is converted into the absolute scale.

Local homogeneous Froude number, Fr_i :

$$Fr_i = \frac{V_i^{\,2}}{gD} \qquad (i = 1, \ldots, 9)$$

where V_i is the average mixture velocity

$$V_i = \frac{W}{\bar{\rho}_i A_o}$$

where $\bar{\rho}_i$ is the homogeneous fluid density, as defined in reference C1, page 29:

$$\bar{\rho}_i = \frac{1}{\dfrac{x_{bi}}{\rho_{gi}} + \dfrac{(1 - x_{bi})}{\rho_{Li}}} \tag{3.17}$$

Therefore $$Fr_i = \frac{1}{gD}\left(\frac{W}{A_o}\right)^2 \left(\frac{x_{bi}}{\rho_{gi}} + \frac{(1 - x_{bi})}{\rho_{Li}}\right)^2 \tag{3.18}$$

Local liquid phase Froude number, Fr_{Li}

$$Fr_{Li} = \frac{1}{gD}\left(\frac{W(1 - x_{bi})}{\rho_L A_O}\right)^2 \tag{3.19}$$

Local vapour phase Froude number, Fr_{gi}

$$Fr_{gi} = \frac{1}{gD}\left(\frac{Wx_{bi}}{\rho_g A_o}\right)^2 \tag{3.20}$$

Local liquid phase Reynolds number, Re_{Li}

$$Re_{Li} = \frac{4W(1 - x_{bi})}{\pi D \mu_{Li}} \tag{3.21}$$

Local vapour phase Reynolds number, Re_{gi}

$$Re_{gi} = \frac{4W\, x_{bi}}{\pi D \mu_{gi}} \tag{3.22}$$

Local liquid phase heat transfer coefficient h_{Li}

It is calculated by means of a Dittus-Boelter type equation:

$$h_{Li} = 0.023 \left(\frac{k_{Li}}{D}\right) Re_{Li}^{\ 0.8}\ Pr_{Li}^{\ 0.4} \tag{3.23}$$

3.3.4. Length-mean heat transfer coefficients and related quantities

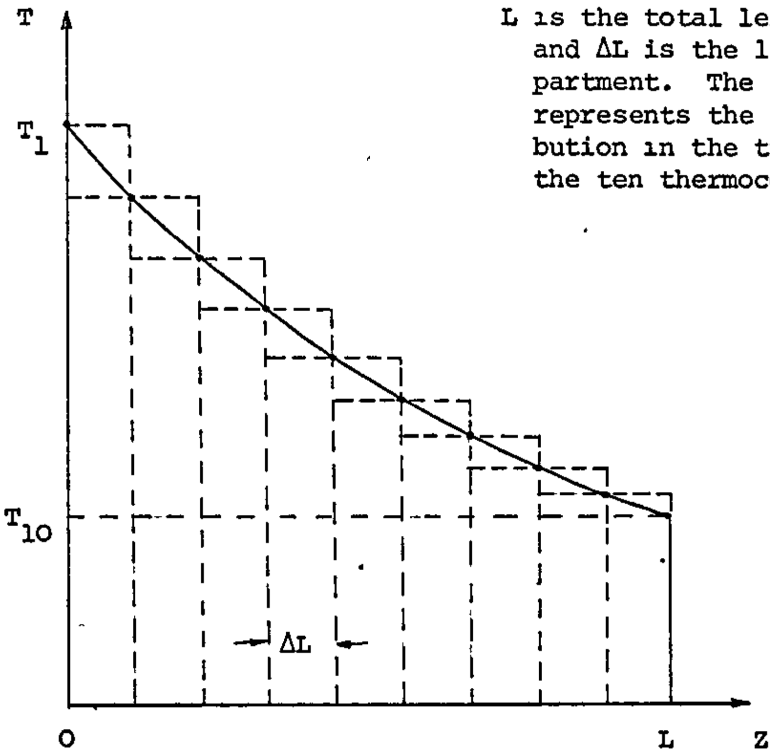
The procedure for the calculation of length-mean coefficients is similar to that already described for the local coefficients.

Length-mean bulk fluid temperature, $\overline{T}_b$

An exact calculation of the length-mean temperature would require the evaluation of the integral:

$$\overline{T}_b = \frac{1}{L}\int_0^L T_b \, dz$$

As no relationship between T_b and the test section height Z is available, an approximate method is used to calculate $\overline{T}_b$.



L is the total length of the tube, and ΔL is the length of each compartment. The accompanying sketch represents the temperature distribution in the tube, obtained from the ten thermocouples.

From this sketch it may be deduced that:

$$\bar{T}_b = \frac{\sum_{i=1}^{9} (T_i + T_{i+1})}{18} \tag{3.24}$$

<u>Length-mean overall temperature driving force, $\Delta\bar{T}_{ov}$</u>

$$\Delta\bar{T}_{ov} = T_s - \bar{T}_b \tag{3.25}$$

<u>Length-mean heat flux, $\bar{q}$</u>

$$\bar{q} = Q/A \tag{3.26}$$

where A is the inside heat transfer area of the whole test section.

Length-mean overall heat transfer coefficient, $\bar{U}$

$$\bar{U} = \bar{q}/\Delta\bar{T}_{ov} \tag{3.27}$$

Length-mean two phase heat transfer coefficient, $\bar{h}_{TP}$

$$\bar{h}_{TP} = \bar{q}/\Delta\bar{T}_{ov} \tag{3.28}$$

where the thermal conductivity $\bar{k}_s$ of the test section material is calculated by means of equation 3.11b, in which $\bar{T}_b$ is used instead of T_{bi}. $\bar{h}_s$ is calculated by means of equation 3.11a, in which $\bar{q}$ replaces q_i.

Length-mean quality, $\bar{x}$

$\bar{x}$ can be obtained by a procedure similar to that used in calculating $\bar{T}_b$. Using the calculated quality distribution 3.12 , the average is:

$$\bar{x} = \frac{\sum_{i=1}^{9} (x_i + x_{i+1})}{18} \tag{3.29}$$

Lockhart-Martinelli parameter, $^1/X_{tt}$

$$\frac{1}{X_{tt}} = \left(\frac{\bar{x}}{1-\bar{x}}\right)^{0.9} \left(\frac{\rho_L}{\rho_g}\right)^{0.5} \left(\frac{\mu_g}{\mu_L}\right)^{0.1} \tag{3.30}$$

The physical properties are calculated at the mean fluid temperature of the test section, $\bar{T}_b$.

Film temperature difference, $\Delta\bar{T}_f$

$$\Delta\bar{T}_f = \bar{q}/\bar{h}_{TP} \tag{3.31}$$

Dimensionless reciprocal of the film temperature difference

It is calculated by evaluating the expression:

$$\overline{T}_b / \Delta\overline{T}_f \qquad (3.32)$$

in which $\overline{T}_b$ is an absolute temperature.

Homogeneous Froude number, $\overline{Fr}$

$$\overline{Fr} = \frac{1}{gD}\left(\frac{W}{Ao}\right)^2 \left(\frac{\overline{x}}{\rho_g} + \frac{(1-\overline{x})}{\rho_L}\right)^2 \qquad (3.33)$$

Liquid phase Froude number, $\overline{Fr}_L$

$$\overline{Fr}_L = \frac{1}{gD}\left(\frac{W\ (1-\overline{x})}{\rho_L A_o}\right)^2 \qquad (3.34)$$

Vapour phase Froude number, $\overline{Fr}_g$

$$\overline{Fr}_g = \frac{1}{gD}\left(\frac{W\overline{x}}{\rho_g A_o}\right)^2 \qquad (3.35)$$

Liquid phase Reynolds number, $\overline{Re}_L$

$$\overline{Re}_L = \frac{4W\ (1-\overline{x})}{\pi D \mu_L} \qquad (3.36)$$

Vapour phase Reynolds number, $\overline{Re}_g$

$$\overline{Re}_g = \frac{4W\overline{x}}{\pi D \mu g} \qquad (3.37)$$

Liquid phase heat transfer coefficient, $\bar{h}_L$

$$\bar{h}_L = 0.023 \left(\frac{k_L}{D}\right) \bar{Re}_L^{\;0.8} \; Pr_L^{\;0.4} \qquad (3.38)$$

3.4. Error estimation

Errors in the experimental heat transfer coefficients and other derived quantities arise from errors in measurement and from errors in the measuring instruments.

3.4.1. Errors in reading of temperatures

Steam temperature, T_s

The temperature and pressure of the heating steam were fixed by means of a reducing valve.

The thermometer used to measure T_s had the temperature scale in $0.2^{\circ}C$ divisions. Hence, the reading error in T_s was taken as $\pm 0.2^{\circ}C$.

Process fluid temperatures, T_l

These temperatures were measured by means of thermocouples. The e.m.f. readings taken by the digital voltmeter and recorded by the typewriter connected to it had an accuracy of ±0.01mV. It is estimated that in the process of averaging not less than ten readings for each thermocouple the error in T_l is reduced to ±0.005mV, which corresponds to an error in temperature of $\pm 0.125^{\circ}C$.

The calibration and reading errors of the cold junction thermometer were estimated to be of ±0.2°C.

The thermometer used in the calibration of the thermocouples had an accuracy of ±0.1°C. The sum of these partial errors is:

$$\pm 0.125 \pm 0.2 \pm 0.1 = \pm 0.42^{\circ}C.$$

3.4.2. Errors in flow measurements

The liquid and vapour flow rates, W_L and W_g are subject to flow fluctuations. The length of the cycle of the fluctuations was about one second. The time of collecting the samples of condensate was approximately 40 seconds, and that of collecting the circulating liquid samples ranged from 5 to 30 seconds. It is therefore assumed that these samples represented average flow of the two streams.

Condensate flow rate, W_g

The stop watch used to measure times of collection of condensate was read with an accuracy of ±0.1 second, while the times of collection were not less than 40 seconds, therefore the maximum error in timing was:

$$\frac{\pm 0.1}{40} \times 100 = \pm 0.25\%$$

The collected volume of condensate was always of about 400cm³. The error in reading the liquid level in the measuring cylinder was ±2cm³. The error in volume measurement is:

$$\frac{\pm 2}{400} \times 100 = \pm 0.5\%$$

The total measurement error in the vapour condensate flow rate is:

$$\pm 0.25 \pm 0.5\% = \pm 1.4\%$$

Liquid flow rate, W_L

The time of collection of approximately 1 litre of circulating liquid in the measuring cylinder varied with the liquid flow rate. Times ranging from 5 to 30 seconds were used. For most of the runs the time of collection was over 8 seconds, therefore the timing error is:

$$\frac{\pm 0.1}{8} \times 100 = 1.25\%$$

The height of liquid in the measuring cylinder could be measured to ±1mm, which corresponds to a volume of about $5cm^3$. Samples of over 1 litre were taken for all runs. The error therefore is:

$$\frac{\pm 5}{1000} \times 100 = \pm 0.5\%$$

The total measurement error in W_L is:

$$\pm 1.25 \pm 0.5\% = \pm 1.75\%$$

Total mass flow rate, W

The total error in W is the sum of the errors in W_g and W_L:

$$\frac{\delta W}{W} = \frac{\delta W_g}{W_g} + \frac{\delta W_L}{W_L}$$

$$= 0.75\% + 1.75\% = 2.5\%$$

Errors in the exit quality, x_{10}

$$x_{10} = W_g/W$$

$$\frac{\delta x_{10}}{x_{10}} = \frac{\delta W_g}{W_g} + \frac{\delta W}{W}$$

$$= 0.75\% + 2.5\% = 3.25\%.$$

3.4.3. Errors in the total heat transferred to the evaporating fluid, Q

From the heat balance,

$$Q = W_g (H_{g10} - H_{L10}) + W (H_{L10} - H_{L1}) \qquad (3.3)$$

$H_{Lg10} = H_{g10} - H_{L10}$ is the latent heat of evaporation which for the calculation of errors is assumed to be constant and equal to 971 BTU/lb. The difference of liquid enthalpies can be expressed as:

$$H_{L10} - H_{L1} = C_P(T_{10} - T_1)$$

where C_P= 1.0085 BTU/lb^{o}F, from Appendix I, equation I.4. Differentiating equation 3.3, the absolute error in Q can be expressed as:

$$\delta Q = H_{Lg10}\ \delta W_g + C_P(T_{10} - T_1)\ \delta W + WC_P\delta(T_{10} - T_1) \qquad (3.39)$$

From previous calculations:

$$\frac{\delta W_g}{W_g} = \pm 0.0075$$

$$\frac{\delta W}{W} = \pm 0.025$$

$$\delta T_{10} = \delta T_1 = \pm 0.42^{\circ}C$$

$$\delta(T_{10} - T_1) = \pm 0.42 \pm 0.42 = \pm 0.84^{\circ}C = \pm 1.51^{\circ}F$$

The error in Q was calculated for a number of representative runs by means of equation 3.39. The results are shown in Table 3.5.

The length-mean heat flux is given by:

$$\bar{q} = Q/A$$

Assuming that the error in the value of the total heat transfer area A is negligible:

$$\frac{\delta \bar{q}}{\bar{q}} = \frac{\delta Q}{Q}$$

Therefore, the error in length-mean heat flux is equal to the error in Q.

3.4.4. Errors in the overall length-mean heat transfer coefficients, $\bar{U}$

By definition:

$$\bar{U} = \frac{Q}{A\,\Delta \bar{T}_{ov}} \qquad (3.40)$$

By differentiation of equation 3.40 it can be shown that:

$$\delta \bar{U} = \frac{1}{A}\left[\frac{\delta Q}{\Delta \bar{T}_{ov}} \pm \frac{Q}{\Delta \bar{T}_{ov}^{\,2}}\ \delta(\Delta \bar{T}_{ov})\right] \qquad (3.41)$$

Table 3.5

Errors in Length-mean Quantities - I

Run Number	W lb/hr	δW lb/hr	W_g lb/hr	δW_g lb/hr	$T_{10}-T_1$ $^\circ F$	$WC_p\delta(T_{10}-T_1)$ BTU/hr	$C_p(T_{10}-T_1)\,\delta W$ BTU/hr	$H_{Lg}\,\delta W_g$ BTU/hr	δQ BTU/hr	Q BTU/hr	$\delta Q/Q$
8	898.0	22.45	41.4	0.311	5.35	1367.5	121.1	301.5	±1790.1	35339.1	±0.0506
16	1100.4	27.50	53.7	0.403	5.94	1678.0	164.7	391.3	±2234.0	45542.1	±0.0490
26	1224.7	30.60	62.2	0.466	6.06	1867.5	187.2	452.5	±2507.2	52805.1	±0.0470
33	1008.9	25.20	73.5	0.511	7.47	1538.4	189.8	496.2	±2224.4	63691.8	±0.0340
52	1185.2	29.63	85.5	0.641	8.91	1804.8	266.2	622.6	±2693.6	72219.9	±0.0373
69	1201.2	30.03	94.0	0.705	9.54	1829.2	291.5	684.5	±2805.2	79630.4	±0.0352
73	746.0	18.65	95.0	0.713	5.63	1136.0	105.9	691.8	±1933.7	86723.4	±0.0223

As $\Delta\overline{T}_{ov} = T_s - \overline{T}_b$, the absolute error in the overall temperature difference $\Delta\overline{T}_{ov}$ is:

$$\delta(\Delta\overline{T}_{ov}) = \delta T_s \pm \delta\overline{T}_b = \pm 0.2 \pm 0.42^{o}C = \pm 0.62^{o}C = \pm 1.116^{o}F$$

The errors in $\overline{U}$ are shown in Table 3.6.

3.4.5. Errors in length-mean coefficients of heat transfer, h_{TP}

The two-phase heat transfer coefficients are calculated from:

$$\frac{1}{\overline{h}_{TP}} = \frac{1}{\overline{U}} - \frac{0.00502}{\overline{k}_s} - \frac{0.871}{\overline{h}_s} \qquad (3.11)$$

where $\overline{k}_s$, the thermal conductivity of the test section material is given by equation 3.11b which gives a 5% accuracy in the value of $\overline{k}_s$ (A1). The heat transfer coefficient for condensing steam is given by equation 3.11a, with an error of ±20% (A1). By differentiation of equation 3.11:

$$\delta\left(\frac{1}{\overline{h}_{TP}}\right) = -\frac{\delta\overline{U}}{\overline{U}^2} + 0.00502\frac{\delta\overline{k}_s}{\overline{k}_s^{\,2}} + 0.871\frac{\delta\overline{h}_s}{\overline{h}_s^{\,2}}$$

For $\overline{k}_s = 10$ BTU/hr ft ^{o}F

$$\frac{\delta\overline{k}_s}{\overline{k}_s^{\,2}} = \frac{(\pm 0.05)\ 10}{100} = \pm 0.005\ \frac{\text{hr ft}\ ^{o}F}{\text{BTU}}$$

For $\overline{h}_s = 3000$ BTU/hr ft² ^{o}F

$$\frac{\delta\overline{h}_s}{\overline{h}_s} = \frac{(\pm 0.2)(3000)}{(3000)^2} = \pm 0.66 \times 10^{-4}\ \frac{\text{hr ft}^2\ ^{o}F}{\text{BTU}}$$

Therefore:

$$\delta\left(\frac{1}{\overline{h}_{TP}}\right) = -\frac{\delta\overline{U}}{\overline{U}^2} \pm 8.3 \times 10^{-5} \qquad (3.43)$$

Table 3.6

Errors in Length-mean Quantities - II

Run Number	$\Delta\overline{T}_{ov}$ ^{o}F	$\delta\overline{U}$ $\frac{BTU}{hr\ ft^2\ ^{o}F}$	$\overline{U}$ $\frac{BTU}{hr\ ft^2\ ^{o}F}$	$\delta\overline{U}/\overline{U}$	$(\delta\overline{U}/\overline{U}^2)\times10^4$ $\frac{hr\ ft^2\ ^{o}F}{BTU}$	$\delta(1/\overline{h}_{TP})\times10^4$ $\frac{hr\ ft^2\ ^{o}F}{BTU}$	$\overline{h}_{TP}$ $\frac{BTU}{hr\ ft^2\ ^{o}F}$	$\frac{\delta\overline{h}_{TP}}{\overline{h}_{TP}}$	$\frac{\delta(\Delta\overline{T}_f)}{\Delta\overline{T}_f}$
8	38.3	±52.9	663.0	±0.0798	±1.20	±2.03	1320.9	±0.268	±0.318
16	46.6	±51.3	702.9	±0.0729	±1.03	±1.86	1496.4	±0.278	±0.327
26	53.3	±48.7	712.6	±0.0683	±0.95	±1.78	1548.7	±0.275	±0.322
33	63.9	±37.5	716.9	±0.0524	±0.73	±1.56	1579.1	±0.246	±0.280
52	70.5	±39.2	737.1	±0.0531	±0.72	±1.55	1695.6	±0.263	±0.300
69	78.0	±36.3	733.8	±0.0495	±0.67	±1.50	1688.9	±0.253	±0.288
73	86.4	±25.4	722.1	±0.0352	±0.49	±1.32	1638.4	±0.216	±0.238

The error in $\bar{h}_{TP}$ is calculated as follows:

$$d\left(\frac{1}{\bar{h}_{TP}}\right) = -\frac{1}{\bar{h}_{TP}^{2}} \, d\,\bar{h}_{TP}$$

$$\frac{\delta\bar{h}_{TP}}{\bar{h}_{TP}} = \bar{h}_{TP}\,\delta\left(\frac{1}{\bar{h}_{TP}}\right) \qquad (3.44)$$

Values of $\delta\bar{U}/\bar{U}^2$, $\delta(1/\bar{h}_{TP})$ and $\delta\bar{h}_{TP}/\bar{h}_{TP}$ are given in Table 3.6.

3.4.6. Errors in the correlating parameters

Lockhart-Martinelli parameter, $1/X_{tt}$

From equation

$$\frac{1}{X_{tt}} = \left(\frac{\bar{x}}{1-\bar{x}}\right)^{0.9}\left(\frac{\rho_L}{\rho_g}\right)^{0.5}\left(\frac{\mu_g}{\mu_L}\right)^{0.9}$$

It is assumed that the error in length-mean quality, $\bar{x}$, is approximately equal to the error in the exit quality, x_{10}. Assuming that the errors in the evaluation of physical properties can be neglected:

$$\frac{\delta(1/X_{tt})}{1/X_{tt}} = \frac{0.9}{x\,(1-\bar{x})}\;\delta\bar{x} = \frac{0.9}{(1-\bar{x})}\left(\frac{\delta\bar{x}}{\bar{x}}\right) = \frac{0.9}{(1-\bar{x})}\;\frac{\delta x_{10}}{x_{10}}$$

$$\frac{\delta(1/X_{tt})}{1/X_{tt}} = \frac{(0.9)\,(0.0325)}{(1-\bar{x})} = \frac{0.02925}{1-\bar{x}} \qquad (3.45)$$

The errors in $1/X_{tt}$ are shown in Table 3.7.

Table 3.7

Errors in the Lockhart-Martinelli Parameter

Length-mean quality, $\bar{x}$	$\frac{\delta(1/X_{tt})}{1/X_{tt}}$
0.02	0.0298
0.04	0.0304
0.06	0.0311
0.08	0.0318
0.40	0.0325
0.12	0.0332
0.14	0.0340
0.16	0.0348

Homogeneous Froude number, $\overline{Fr}$

$$\overline{Fr} = kW^2 \left(\frac{\bar{x}}{\rho_g} + \frac{(1 - \bar{x})}{\rho_L} \right)^2 \tag{3.46}$$

It can be shown that:

$$\frac{\delta \overline{Fr}}{\overline{Fr}} = 2 \frac{\delta W}{W} + 2 \frac{\delta \bar{x}}{\left(\bar{x} + \frac{\rho_g}{(\rho_l - \rho_g)} \right)} \tag{3.47}$$

The term $\rho_g/(\rho_L - \rho_g)$ is negligible with respect to $\bar{x}$ and therefore it is ignored. The error in $\overline{Fr}$ is:

$$\frac{\delta \overline{Fr}}{\overline{Fr}} = 2 \frac{\delta W}{W} + 2 \frac{\delta \bar{x}}{\bar{x}} = 2 \frac{\delta W}{W} + \frac{\delta x_{10}}{x_{10}} \tag{3.48}$$

Using the already calculated errors in W and x_{10}, it can be seen that:

$$\frac{\delta\overline{Fr}}{\overline{Fr}} = 2 \times 0.025 \pm 2 \times 0.032 = \pm 0.115.$$

Liquid and vapour phase Froude numbers, $\overline{Fr}_L$ and $\overline{Fr}_g$

The relative errors in $\overline{Fr}_L$ and $\overline{Fr}_g$ can be calculated by means of equation 3.48, and are therefore equal to the error in $\overline{Fr}$.

Film temperature difference, $\Delta\overline{T}_f$

As $$\Delta\overline{T}_f = \frac{\bar{q}}{\bar{h}_{TP}}$$

$$\frac{\delta(\Delta\overline{T}_f)}{\Delta\overline{T}_f} = \frac{\delta\bar{q}}{\bar{q}} + \frac{\delta\,\bar{h}_{TP}}{\bar{h}_{TP}}$$

$$\frac{\delta(\Delta\overline{T}_f)}{\Delta\overline{T}_f} = \frac{\delta Q}{Q} + \frac{\delta\,\bar{h}_{TP}}{\bar{h}_{TP}}$$

Values of the error in this quantity are given in Table 3.6.

3.4.7. Errors in local heat transfer coefficients, h_{TPi}

Errors in the local coefficients are calculated in the same manner as those for the length-mean coefficients, except that one additional error of measurement has to be included. This is the error in the measurement of the steam condensate from the individual compartments.

The following items of heat losses will be assumed as having no effect on the error in the coefficients. Firstly, heat losses in the flanges joining together the different compartments increase the condensate output. As the steam temperature is the same in all jackets the heat losses in all flanges are equal. Secondly, some condensate evaporates on release from the steam traps to atmospheric conditions. The percentage of condensate that undergoes this flash evaporation depends on the difference between the saturation temperatures before and after the release from the trap. In every single run this difference is the same for all the traps. Consequently, the same percentage of the condensate released by every trap is lost.

The measurement error in the steam condensate is calculated as follows. When measuring the steam condensate flow rates, the collected volume of condensate from each trap was about 2000cm³. The error in reading the liquid level in the measuring cylinder was ±2cm³. Therefore, the error in volume measurement is:

$$\frac{\pm 2}{2000} \times 100 = \pm 0.1\%$$

The collection times of about 30 minutes were measured with an accuracy of ±0.1 seconds. The error in timing is:

$$\frac{\pm 0.1}{30 \times 60} \times 100 = \pm 0.0055\%$$

Therefore the total error in the steam condensate flow rate in each compartment is ±0.95%.

The corrected heat transfer rate to the process liquid is obtained from the following equation discussed in Section 3.3.

$$Q_i = Q_i' \frac{Q}{Q'} \tag{3.8}$$

where $Q_i' = W_{si} H_{Lg}$

$Q' = (\Sigma W_{si}) H_{Lg}$

and Q is given by the heat balance, equation 3.3. It can be shown that:

$$\frac{\delta Q_i}{Q_i} = \pm \frac{\delta W_{si}}{W_{si}} \pm \frac{\delta(\Sigma\, W_{si})}{\Sigma\, W_{si}} \pm \frac{\delta Q}{Q}$$

$$= \pm 0.1055\% \pm 0.95\% \pm \frac{\delta Q}{Q}$$

$$= 1.055\% \pm \frac{\delta Q}{Q}$$

After considering the error in Q_i, the procedure for calculating errors in local quantities is the same as for length-mean ones. Errors in U_i, $1/h_{TPi}$ and h_{TPi} for the middle compartment of the evaporator tube are given in Table 3.8. From Tables 3.6 and 3.8 we see that the errors in the local h_{TP} and the length-mean h_{TP} correlate with the heat flux. These errors are plotted therefore against heat flux in Figure 3.5. The curve for the errors in the local coefficients follows the same pattern as that for the length-mean coefficients. However, the errors in the local coefficients are slightly higher than those for the length-mean coefficients.

3.4.8. Repeatability of experimental results

It was almost impossible to make two runs under exactly the same conditions of submergence and steam temperature. Table 3.9 compares local quantities in the middle compartments of the evaporator tube for pairs of runs in which approximately the same conditions were obtained. The magnitude of the deviations shown in the last column of Table 3.9 is relatively small compared with the experimental error in the corresponding quantities.

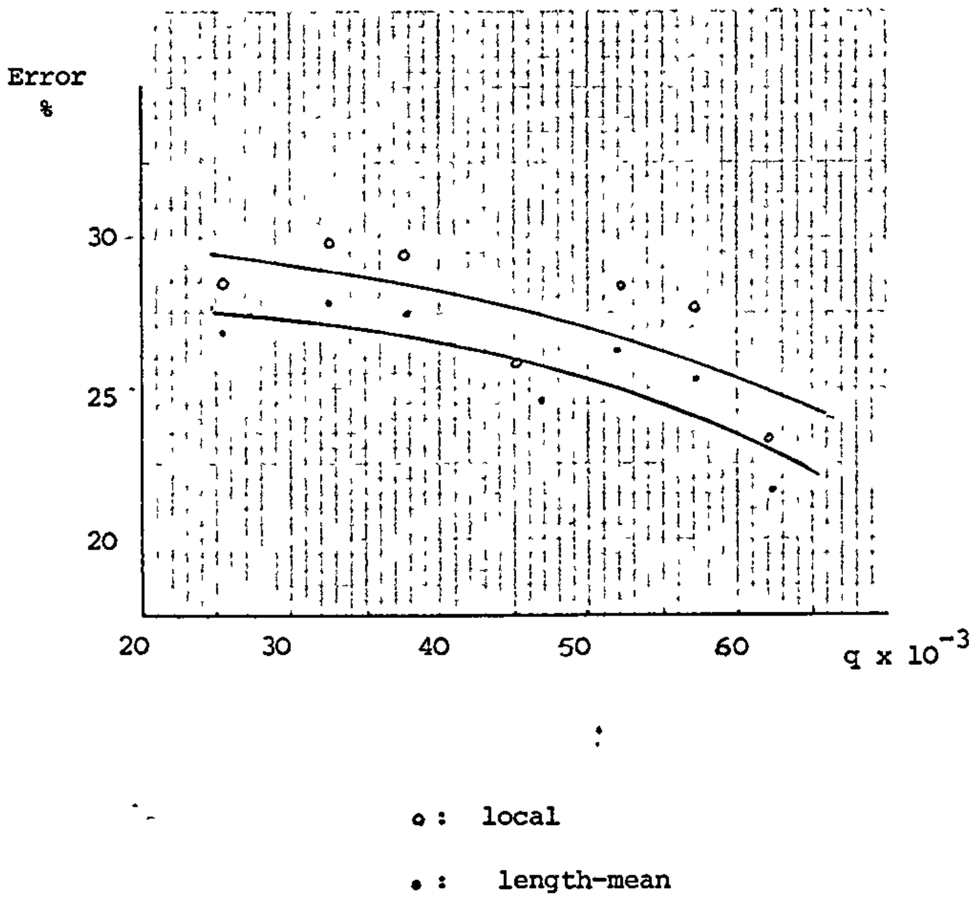


Fig. 3.5. Errors in two phase film heat transfer coefficients versus heat flux.

Table 3.8

Errors in Local Quantities (Middle compartment of the test section)

Run Number	$\frac{\delta Q_i}{Q_i}$	U_i	ΔT_{ovi} ^oF	δU_i	$\delta U_i/U_i$	$\delta U_i/U_i^2 \times 10^4$	$\delta\left(\frac{1}{h_{TPi}}\right) \times 10^4$	h_{TP}	$\frac{\delta h_{TPi}}{h_{TPi}}$
8	0.0611	657.0	38.70	±59.12	±0.0899	±1.37	±2.20	1297.3	±0.285
16	0.0595	698.2	46.89	±58.19	±0.0833	±1.19	±2.02	1477.8	±0.298
26	0.0575	706.1	53.42	±55.38	±0.0784	±1.11	±1.94	1518.9	±0.294
33	0.0445	702.3	64.22	±43.49	±0.0619	±0.88	±1.71	1512.3	±0.258
52	0.0478	734.2	70.76	±46.71	±0.0636	±0.86	±1.69	1681.5	±0.284
69	0.0457	731.9	78.05	±43.94	±0.0600	±0.82	±1.65	1677.8	±0.277
73	0.0328	710.5	87.28	±32.42	±0.0456	±0.64	±1.47	1579.0	±0.232

Table 3.9

Repeatability of Results

Quantity	Run 29 T_s = 139.83°C S = 45%	Run 30 T_s = 139.8°C S = 46%	Deviation on the basis of Run 29, %
x_{10}	0.11349	0.11450	0.89
q, $\frac{BTU}{hr\ ft^2}$	44476	44507	0.069
h_{TP}, $\frac{BTU}{hr\ ft^2\ {}^oF}$	1338.2	1343.8	0.418
$1/X_{tt}$	2.083	2.137	2.59
$T_b/\Delta T_f$	20.36	20.43	0.34
Fr	1143.5	1203.7	5.26
Fr_L	0.168	0.167	-0.60
Quantity	Run 48 T_s = 143.9°C S = 70%	Run 49 T_s = 143.5°C S = 71%	Deviation on the basis of run 48, %
x_{10}	0.08683	0.08284	-4.59
q $\frac{BTU}{hr\ ft^2}$	51257	50428	-1.62
h_{TP} $\frac{BTU}{hr\ ft^2\ {}^oF}$	1530.0	1521.6	-0.55
$1/X_{tt}$	1.541	1.463	-5.06
$T_b/\Delta T_f$	20.25	20.47	1.08
Fr	1407.6	1363.5	-3.13
Fr_L	0.412	0.45	9.22

/continued

Table 3.9 (continued)

Quantity	Run 59 T_s = 148.9°C S = 61%	Run 60 T_s = 148°C S = 61%	Deviation on the basis of run 59, %
x_{10}	0.12780	0.12224	-4.35
$q \frac{BTU}{hr\ ft^2}$	56844	56229	-1.08
$h_{TP} \frac{BTU}{hr\ ft^2\ {}^\circ F}$	1473.3	1487.0	0.93
$1/X_{tt}$	2.311	2.191	-5.19
$T_b/\Delta T_f$	17.56	17.91	1.99
Fr	1790.2	1675.2	-6.42
Fr_L	0.213	0.223	4.69

4. Experimental Results

The experimental part of this work consisted of 85 runs with distilled water on the nine-compartment reboiler apparatus described in the preceding chapter.

The independent variables were the heating steam temperature and the submergence. Table 4.1 shows the distribution of the runs in the ranges of independent variables used in this work.

The method of operation of the apparatus and of taking experimental measurements is presented in Chapter 3. Local and length-mean heat transfer coefficients and other derived quantities were calculated by means of the equations in Section 3.3. Sample calculations are given in Appendix III.

The heat transfer results are summarized in Table 4.2, which gives the ranges of the pertinent variables. Table 4.3 shows the experimental conditions under which all the runs were carried out. Detailed length-mean results are reported in Tables 4.4 and 4.5. Finally, the local heat transfer results can be found in Tables 4.6 and 4.7.

Table 4.1

Number of Runs Carried Out Within the Range of Experimental Variables Shown

T_s, °C / Submergence, %	115-120	120-125	125-130	130-135	135-140	140-145	145-150	150-152	Total
20-30	-	-	-	-	-	-	1	5	6
30-40	-	-	-	1	1	1	3	5	11
40-50	-	1	-	-	2	3	1	1	8
50-60	1	1	-	1	1	2	2	1	9
60-70	-	2	2	2	2	-	3	-	11
70-80	3	2	2	1	4	3	5	2	22
80-90	1	1	-	1	3	1	2	-	9
90-100	2	1	2	-	1	2	1	-	9
Total	7	8	6	6	14	12	16	14	85

Table 4.2

Summary of Experimental Results

Quantity	Range Covered	
Steam temperature, T_s, ^oC	117.45-151.4	
Submergence, %	24-104	
Heat flow, Q, BTU/hr	23811-86723	
Mass flow, W, lb/hr	233.5-2080.8	
Mass flux, G; lb/hr ft²	$5.6x10^4$-$50.2x10^4$	
Exit quality, x_{10}	0.0197-0.3620	
Quantity	**Length-mean range**	**Local range**
Overall temperature difference, ΔT_{ov}, ^oF	25.94-90.23	23.40- 91.29
Film temperature difference, ΔT_f, ^oF	12.41-45.15	12.06-51.45
Heat flux, q, BTU/hr ft²	17127-62378	15223-69194
Quality, x	0.0080-0.1744	0.00027-0.33824
Two-phase heat transfer coefficient h_{TP}, BTU/hr ft² ^oF	1005.3-1940.1	830.5-2344.8
Liquid phase heat transfer coefficient, h_L, BTU/hr ft² ^oF	142.3-955.0	119.0-966.0
h_{TP}/h_L	1.433-9.233	1.161-13.893
Lockhart-Martinelli parameter, $1/X_{tt}$	0.361-7.024	0.017-15.665
Dimensionless reciprocal film temperature difference, $T_b/\Delta T_f$	14.92-53.19	13.06-60.11
Homogeneous Froude number, Fr	245.8-2294.0	1.7-9209.5
Liquid Froude number, Fr_L	0.020-2.298	0.013-2.337
Vapour Froude number, Fr_g	211.4-2245.0	0.2-9117.1

Tables of Length-Mean Results (4.3, 4.4, 4.5)

S:	Submergence	per cent
T_s:	Steam temperature	^oC
x_{10}:	Exit quality	-
W:	Total flow rate	lb/hr
Q:	Total heat transferred along the whole length of the tube	BTU/hr
$\bar{T}_b$:	Length-mean bulk fluid temperature	^oC
$\bar{x}$:	Length-mean quality	-
$\bar{q}$:	Heat flux	BTU/hr ft²
$\bar{h}_{TP}$:	Two-phase heat transfer coefficient	BTU/hr ft² ^oF
$\bar{h}_L$:	Liquid phase heat transfer coefficient	BTU/hr ft² ^oF
$1/X_{tt}$:	Lockhart-Martinelli parameter	-
$\Delta\bar{T}_f$:	Film temperature difference	^oF
$\frac{\bar{T}_b}{\Delta\bar{T}_f}$:	Dimensionless reciprocal of the film temperature difference	-
$\bar{Fr}$:	Homogeneous Froude number	-
$\bar{Fr}_L$:	Liquid phase Froude number	-
$\bar{Fr}_g$:	Vapour phase Froude number	-

Table 4.3

Experimental Conditions of the 85 runs

Run No.	S	T_s	x_{10}	W	Q
1	51	118.25	0.03244	944.980	25940.8
2	70	117.45	0.02270	1507.294	23811.7
3	72	118.55	0.02163	1563.556	26304.7
4	73	118.75	0.02355	1700.806	26968.9
5	83	119.75	0.02569	1943.885	31146.8
6	90	118.75	0.01977	2080.768	26244.7
7	93	118.40	0.02263	2034.699	26776.8
8	47	123.80	0.04615	898.036	35339.1
9	51	123.95	0.04500	905.366	35737.0
10	60	124.50	0.03987	1142.741	36853.4
11	62	124.45	0.03371	1256.808	36900.5
12	72	123.55	0.03199	1416.810	36035.9
13	78	124.20	0.02989	1607.775	36316.7
14	88	123.75	0.02663	1922.870	36583.3
15	90	125.35	0.02769	1902.595	38828.2
16	61	128.85	0.04887	1100.438	45542.1
17	64	130.90	0.04874	1161.410	48038.4
18	73	129.50	0.04211	1361.350	47944.9
19	75	129.60	0.04103	1359.824	46281.8
20	90	129.40	0.03838	1654.417	46001.9
21	97	129.50	0.03875	1760.699	48843.5
22	38	133.35	0.10586	521.552	51246.0
23	53	133.30	0.06706	855.167	51062.4
24	65	132.70	0.05525	1079.459	53037.3
25	67	133.00	0.04488	1125.452	42962.1
26	71	133.35	0.05081	1224.754	52805.1
27	88	133.35	0.04848	1425.380	54820.2
28	37	139.45	0.13966	465.791	61285.5
29	45	139.83	0.11349	589.551	61976.8
30	46	139.80	0.11450	589.060	62432.6
31	51	139.70	0.09727	699.356	62652.3

/Continued

Run No.	S	T_s	x_{10}	W	Q
32	64	139.70	0.07695	907.128	63656.8
33	69	139.15	0.07290	1008.910	63691.8
34	71	140.50	0.07458	999.497	65946.1
35	73	138.00	0.05805	1082.666	55923.0
36	75	138.70	0.06683	1092.854	63888.5
37	79	139.60	0.06757	1137.467	64947.2
38	84	139.78	0.05665	1258.552	63354.3
39	85	139.30	0.06707	1163.027	65591.9
40	86	139.55	0.05877	1280.501	64198.6
41	95	139.73	0.06055	1333.434	65256.9
42	33	143.80	0.18891	384.408	68703.4
43	42	143.95	0.14611	497.658	68337.4
44	45	143.85	0.14203	526.937	69786.5
45	48	143.90	0.12732	588.318	69879.4
46	52	143.85	0.11720	644.623	69744.2
47	58	143.40	0.10756	717.995	70424.2
48	70	143.90	0.0863	909.336	71676.7
49	71	143.50	0.08284	947.878	70922.7
50	74	144.75	0.08923	929.146	73774.0
51	85	144.05	0.07560	1100.401	73613.1
52	92	143.68	0.07215	1185.198	72219.9
53	96	143.65	0.07104	1233.803	73657.1
54	27	149.10	0.27299	290.735	75843.7
55	39	147.80	0.18280	431.084	74974.5
56	48	148.00	0.15372	518.375	76854.5
57	55	146.90	0.13396	628.527	77719.6
58	57	148.20	0.13310	640.762	78615.2
59	61	148.90	0.12780	668.814	79375.5
60	61	148.00	0.12224	681.685	78105.6
61	67	147.80	0.11990	722.366	78823.4
62	71	147.80	0.10512	811.923	78720.1
63	75	147.90	0.09782	920.416	79832.2
64	78	147.80	0.09042	951.773	77859.5

/Continued

Run No.	S	T_s	x_{10}	W	Q
65	79	149.45	0.10301	880.798	81739.3
66	79	145.75	0.08628	1012.056	76045.9
67	84	148.93	0.09372	986.730	81382.6
68	89	148.25	0.08780	1037.322	80416.7
69	104	147.93	0.07831	1201.239	79630.3
70	35	150.65	0.25654	337.830	82318.9
71	42	151.10	0.22699	391.343	83973.0
72	56	151.15	0.15853	560.623	83329.6
73	71	151.40	0.12730	745.983	86723.3
74	76	151.40	0.11694	801.333	85308.4
75	35	151.35	0.22734	380.214	82027.0
76	32	151.35	0.26145	331.879	82405.3
77	24	151.35	0.36179	233.513	81066.4
78	29	151.30	0.30321	282.777	81858.9
79	36	151.30	0.23154	379.552	83122.7
80	27	151.20	0.31128	277.029	82398.3
81	33	151.25	0.24083	364.197	83128.7
82	32	147.80	0.23138	330.860	73915.0
83	31	148.75	0.24756	300.415	72864.9
84	28	151.10	0.30712	273.132	80157.6
85	24	151.10	0.33135	254.083	80517.1

Table 4.4

Length-mean Results - I

Run Number	$\bar{T}_b$	$\bar{x}$	$\bar{q}$	$\bar{h}_{TP}$	$\bar{h}_L$	$\frac{\bar{h}_{TP}}{\bar{h}_L}$	$\frac{1}{X_{tt}}$
1	102.01	0.0145	18659.	1220.9	502.3	2.431	0.6361
2	103.04	0.0102	17127.	1301.7	735.8	1.769	0.4535
3	103.08	0.0088	18920.	1380.8	758.7	1.820	0.3959
4	103.35	0.0104	19398.	1467.0	811.5	1.808	0.4602
5	103.52	0.0120	22403.	1804.6	902.7	1.999	0.5204
6	103.25	0.0080	18877.	1368.5	955.0	1.453	0.3614
7	103.32	0.0101	19260.	1512.4	936.8	1.614	0.4487
8	102.50	0.0216	25419.	1320.9	480.6	2.749	0.9073
9	101.68	0.0205	25705.	1237.7	482.3	2.566	0.8780
10	102.24	0.0185	26508.	1316.4	583.5	2.256	0.7924
11	102.67	0.0140	26542.	1379.3	633.2	2.178	0.6080
12	102.30	0.0138	25920.	1380.6	695.8	1.984	0.6064
13	103.19	0.0127	26122.	1436.0	773.8	1.856	0.5534
14	103.52	0.0111	26314.	1582.2	895.5	1.767	0.4851
15	103.42	0.0113	27928.	1513.2	887.3	1.705	0.4961
16	102.94	0.0224	32758.	1496.4	566.2	2.643	0.9334
17	103.18	0.0222	34553.	1453.8	591.9	2.456	0.9211
18	103.44	0.0183	34486.	1656.5	675.1	2.454	0.7684
19	103.56	0.0175	33290.	1532.3	675.3	2.269	0.7361
20	104.51	0.0177	33088.	1669.1	793.4	2.104	0.7347
21	104.67	0.0175	35132.	1940.1	834.7	2.324	0.7260
22	102.06	0.0503	36860.	1298.4	303.2	4.282	2.0092
23	102.87	0.0311	36728.	1362.1	459.3	2.966	1.2643
24	102.94	0.0241	38149.	1549.3	556.8	2.783	0.9961
25	102.99	0.0199	30902.	1005.3	577.8	1.740	0.8368
26	103.73	0.0228	37982.	1548.7	618.9	2.502	0.9350
27	103.90	0.0219	39431.	1709.0	699.8	2.442	0.9011
28	102.31	0.0666	44081.	1324.8	273.5	4.844	2.6186
29	102.65	0.0536	44579.	1353.3	334.4	4.047	2.1151

/continued

Run Number	$\bar{T}_b$	$\bar{x}$	$\bar{q}$	$\bar{h}_{TP}$	$\bar{h}_L$	$\frac{\bar{h}_{TP}}{\bar{h}_L}$	$\frac{1}{X_{tt}}$
30	102.78	0.0546	44907.	1385.9	334.1	4.148	2.1506
31	103.16	0.0455	45065.	1434.9	386.9	3.709	1.7994
32	103.02	0.0347	45787.	1472.8	480.4	3.066	1.3958
33	103.61	0.0339	45812.	1579.1	524.9	3.009	1.3537
34	103.29	0.0339	47434.	1543.9	520.2	2.968	1.3632
35	103.04	0.0252	40224.	1241.9	557.8	2.226	1.0389
36	103.86	0.0306	45954.	1662.3	561.7	2.959	1.2255
37	104.14	0.0314	46715.	1659.2	580.4	2.859	1.2515
38	104.08	0.0242	45569.	1544.9	632.9	2.441	0.9827
39	104.35	0.0309	47179	1756.0	591.6	2.968	1.2296
40	104.09	0.0262	46177.	1615.8	640.7	2.522	1.0583
41	104.43	0.0275	46938.	1694.6	662.1	2.560	1.1033
42	102.21	0.0908	49417.	1334.4	229.6	5.813	3.5489
43	102.96	0.0699	49154.	1358.6	288.4	4.711	2.7150
44	102.92	0.0682	50196.	1424.5	302.3	4.712	2.6530
45	103.13	0.0600	50263.	1440.4	332.8	4.328	2.3381
46	103.11	0.0553	50166.	1436.6	359.4	3.997	2.1662
47	102.93	0.0507	50655.	1488.5	393.0	3.788	1.9980
48	103.51	0.0397	51556.	1553.9	480.5	3.234	1.5717
49	103.64	0.0377	51013.	1562.3	497.8	3.138	1.4955
50	103.88	0.0415	53064.	1616.9	488.9	3.307	1.6298
51	104.04	0.0342	52948.	1688.6	563.6	2.996	1.3588
52	104.53	0.0331	51946.	1695.6	600.0	2.826	1.3070
53	104.55	0.0325	52980.	1783.8	620.0	2.877	1.2851
54	101.87	0.1312	54553.	1266.0	176.7	7.163	6.1805
55	102.32	0.0867	53928.	1333.7	252.6	5.279	3.3870
56	102.22	0.0719	55280.	1386.6	296.4	4.677	2.8231
57	103.41	0.0634	55902.	1585.9	350.3	4.527	2.4556
58	102.97	0.0631	56546.	1493.8	355.1	4.206	2.4597
59	103.20	0.0602	57093.	1491.5	368.8	4.044	2.3445
60	102.99	0.0569	56180.	1487.3	375.1	3.965	2.2271

/continued

Run Number	$\bar{T}_b$	$\bar{x}$	$\bar{q}$	$\bar{h}_{TP}$	$\bar{h}_L$	$\frac{\bar{h}_{TP}}{\bar{h}_L}$	$\frac{1}{X_{tt}}$
61	102.74	0.0571	56696.	1515.0	392.4	3.861	2.2444
62	103.38	0.0486	56622.	1558.3	435.3	3.580	1.9082
63	103.91	0.0453	57422.	1644.7	483.8	3.400	1.7701
64	103.52	0.0405	56003.	1530.1	498.0	3.072	1.6018
65	104.13	0.0475	58793.	1623.6	466.7	3.479	1.8437
66	104.17	0.0398	54698.	1668.6	525.0	3.178	1.5599
67	104.38	0.0438	58537.	1670.7	513.2	3.255	1.7032
68	103.94	0.0408	57842.	1645.4	534.4	3.079	1.6043
69	104.57	0.0356	57276.	1688.9	605.4	2.790	1.3987
70	101.88	0.0227	59210.	1407.7	200.9	7.008	4.8330
71	102.49	0.1091	60400.	1480.0	229.4	6.452	4.2477
72	102.45	0.0751	59937.	1449.6	315.1	4.601	2.959
73	103.41	0.0606	62378.	1638.4	402.7	4.068	2.3529
74	103.52	0.0547	61361.	1584.9	428.8	3.696	2.1275
75	102.52	0.1084	59000.	1392.9	224.3	6.209	4.2159
76	102.19	0.1262	59273.	1387.2	197.7	7.017	4.9489
77	101.70	0.1744	58309.	1313.7	142.3	9.233	7.0238
78	101.17	0.1454	58879.	1314.6	170.1	7.731	5.8338
79	101.92	0.1114	59789.	1400.6	222.8	6.286	4.3770
80	102.28	0.1505	59267.	1400.9	167.3	8.371	5.9404
81	102.22	0.1162	59793.	1421.5	214.9	6.614	4.5458
82	101.64	0.1099	53166.	1257.8	199.6	6.300	4.3360
83	101.33	0.1157	52411.	1160.7	183.6	6.323	4.5946
84	102.51	0.1474	57656.	1339.8	166.1	8.065	5.7914
85	102.10	0.1595	57975.	1332.6	154.7	8.614	6.3368

Table 4.5

Length-mean Results - II

Run Number	$\Delta\overline{T}_f$	$\dfrac{\overline{T}_b}{\Delta\overline{T}_f}$	$\overline{Fr}$	$\overline{Fr}_L$	$\overline{Fr}_g$
1	15.28	44.17	247.6	0.467	226.6
2	13.16	51.44	302.2	1.200	265.4
3	13.70	49.40	245.8	1.295	211.4
4	13.22	51.23	393.0	1.528	345.5
5	12.41	54.59	658.4	1.990	588.0
6	13.79	49.10	359.9	2.298	304.7
7	12.73	53.19	534.1	2.188	467.9
8	19.24	35.12	464.6	0.416	437.2
9	20.77	32.47	452.4	0.423	425.2
10	20.14	33.54	570.3	0.677	531.6
11	19.24	35.14	390.3	0.827	355.2
12	18.77	35.98	499.3	1.051	454.5
13	18.19	37.22	516.9	1.358	465.3
14	16.63	40.75	557.0	1.951	493.0
15	18.46	36.71	572.9	1.908	508.7
16	21.89	30.91	730.1	0.624	688.0
17	23.77	28.49	785.1	0.695	739.0
18	20.82	32.55	730.5	0.963	678.4
19	21.72	31.20	663.7	0.963	614.1
20	19.82	34.28	950.9	1.427	878.7
21	18.11	37.54	1045.5	1.617	964.9
22	28.39	23.78	845.6	0.132	824.6
23	26.96	25.09	838.1	0.370	803.3
24	24.62	27.48	805.8	0.598	762.5
25	30.74	22.02	605.8	0.656	566.6
26	24.53	27.65	885.8	0.773	834.2
27	23.07	29.40	1104.1	1.049	1037.1
28	33.27	20.30	1157.2	0.102	1135.6
29	32.94	20.53	1178.6	0.168	1150.7

/continued

Run Number	$\Delta\overline{T}_f$	$\frac{\overline{T}_b}{\Delta\overline{T}_f}$	$\overline{Fr}$	$\overline{Fr}_L$	$\overline{Fr}_g$
30	32.40	20.88	1212.9	0.167	1184.6
31	31.41	21.56	1164.5	0.2410	1131.3
32	31.09	21.77	1155.6	0.413	1112.3
33	29.01	23.37	1315.2	0.513	1263.7
34	30.72	22.05	1323.2	0.503	1272.1
35	32.39	20.90	882.9	0.600	837.5
36	27.64	24.54	1242.1	0.606	1187.8
37	28.16	24.11	1393.8	0.655	1334.0
38	29.50	23.01	1027.4	0.814	970.4
39	26.87	25.28	1395.1	0.686	1333.9
40	28.58	23.75	1242.9	0.840	1179.1
41	27.70	24.53	1456.2	0.908	1384.4
42	37.03	18.24	1466.0	0.066	1446.4
43	36.18	18.71	1391.0	0.115	1365.8
44	35.24	19.20	1489.7	0.130	1462.0
45	34.89	19.40	1421.7	0.165	1391.2
46	34.92	19.39	1458.3	0.200	1424.4
47	34.03	19.88	1538.6	0.250	1499.6
48	33.18	20.43	1466.7	0.411	1418.0
49	32.65	20.76	1429.9	0.449	1379.7
50	32.82	20.67	1632.8	0.428	1580.3
51	31.36	21.64	1555.5	0.610	1494.5
52	30.64	22.18	1638.4	0.710	1570.9
53	29.70	22.88	1712.3	0.770	1640.4
54	43.09	15.66	1786.5	0.034	1770.9
55	40.44	16.71	1672.2	0.083	1648.7
56	39.87	16.94	1676.5	0.125	1647.7
57	35.25	19.22	1778.5	0.187	1742.3
58	37.85	17.88	1881.9	0.194	1843.8
59	38.28	17.69	1843.5	0.213	1804.1
60	37.77	17.92	1734.4	0.223	1695.3

/continued

Run Number	$\Delta\overline{T}_f$	$\frac{\overline{T}_b}{\Delta\overline{T}_f}$	$\overline{Fr}$	$\overline{Fr}_L$	$\overline{Fr}_g$
61	37.42	17.92	1734.4	0.223	1695.3
62	36.34	18.64	1761.4	0.322	1714.1
63	34.91	19.43	1902.1	0.417	1846.2
64	36.60	18.52	1671.4	0.450	1617.0
65	36.21	18.75	1883.9	0.380	1830.7
66	32.78	20.71	1750.9	0.510	1691.7
67	35.04	19.39	1987.8	0.481	1926.4
68	35.15	19.30	1965.1	0.534	1900.8
69	33.91	20.04	1938.2	0.725	1863.9
70	42.06	16.04	2108.3	0.047	2088.4
71	40.81	16.56	2150.4	0.065	2126.8
72	41.35	16.35	2107.3	0.145	2072.5
73	38.07	17.80	2294.0	0.265	2245.0
74	38.72	17.51	2141.6	0.310	2090.4
75	42.36	15.96	1997.7	0.062	1975.5
76	42.73	15.81	2106.1	0.045	2086.6
77	44.39	15.20	2052.8	0.020	2040.0
78	44.79	15.04	2176.5	0.031	2160.0
79	42.69	15.81	2189.9	0.061	2166.8
80	42.31	15.97	2071.9	0.030	2056.2
81	42.06	16.06	2147.9	0.056	2126.1
82	42.27	15.95	1650.7	0.047	1633.2
83	45.15	14.92	1542.2	0.038	1527.0
84	43.03	15.71	1903.4	0.029	1888.5
85	43.51	15.52	1980.0	0.025	1966.1

Table 4.6

Local Results - I

S:	Submergence	per cent
T_s:	Steam temperature	^oC
i:	Compartment number, counted from the bottom of the tube	-
T_{bi}:	Bulk fluid temperature	^oC
ΔT_{ovi}:	Overall temperature driving force	^oF
W_{Li}:	Liquid mass flow rate	lb/hr
W_{gi}:	Vapour mass flow rate	lb/hr
Re_{Li}:	Liquid phase Reynolds number	-
Re_{gi}:	Vapour phase Reynolds number	-
x_{bi}:	Two-phase mixture quality	-

S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 1 51.	118.25								
		1	103.00	27.45	944.4	0,6	25303.	348.	.00062
		2	102.65	28.08	941.2	3.8	25121.	2254.	.00400
		3	102.36	28.50	938.0	7,0	24958.	4166.	.00739
		4	102.24	28.81	935.0	10,0	24845.	5968.	.01058
		5	101.82	29.57	931.3	13,7	24634.	8171.	.01447
		6	101.71	29.77	928.1	16,9	24520.	10107.	.01789
		7	101.71	29.76	924.9	20,1	24438.	11986.	.02122
		8	101.68	29.82	921.6	23,4	24343.	13968.	.02472
		9	100.91	31.22	916.9	28,1	24016.	16829.	.02972
RUN 2 70.	117.45								
		1	104.45	23.40	1506.3	1,0	41007.	588.	.00066
		2	103.88	24.42	1502.3	5,0	40642.	2992.	.00334
		3	103.64	24.86	1499.1	8,2	40447.	4878.	.00544
		4	103.44	25.21	1496.0	11,3	40278.	6708.	.00748
		5	102.86	26.25	1491.8	15,5	39910.	9244.	.01029
		6	102.63	26.67	1488.4	18,9	39720.	11244.	.01251
		7	102.53	26.86	1485.3	22,0	39592.	13108.	.01458
		8	102.37	27.14	1481.9	25.4	39432.	15163.	.01686
		9	101.51	28.69	1476.3	31,0	38920.	18547.	.02057
RUN 3 72.	118.55								
		1	103.71	26.70	1563.1	0,4	42210.	253.	.00027
		2	103.80	26.55	1560.8	2,8	42185.	1661.	.00179
		3	103.94	26.30	1558.5	5,1	42189.	3017.	.00325
		4	103.68	26.77	1554.9	8,6	41972.	5135.	.00552
		5	103.01	27.97	1550.0	13,5	41534.	8051.	.00865
		6	102.71	28.50	1546.1	17,4	41296.	10385.	.01114
		7	102.67	28.58	1542.8	20,7	41187.	12362.	.01326
		8	102.53	28.84	1539.1	24,5	41022.	14606.	.01566
		9	101.67	30.39	1533.1	30,5	40484.	18234.	.01950

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 4	73.	118.75								
			1	104.82	25.07	1699.7	1.1	46465.	662.	.00066
			2	104.31	25.99	1695.3	5.5	46082.	3247.	.00322
			3	104.08	26.41	1691.8	9.0	45865.	5373.	.00532
			4	103.75	26.99	1687.8	13.0	45596.	7728.	.00764
			5	103.24	27.92	1683.1	17.7	45213.	10527.	.01040
			6	103.03	28.29	1679.3	21.5	45010.	12798.	.01263
			7	102.79	28.72	1675.3	25.5	44785.	15209.	.01500
			8	102.54	29.10	1671.1	29.7	44546.	17726.	.01747
			9	101.54	30.98	1664.5	36.3	43895.	21734.	.02137
RUN 5	83.	119.75								
			1	105.50	25.66	1941.5	2.4	53474.	1438.	.00125
			2	104.50	27.45	1934.7	9.2	52699.	5447.	.00472
			3	104.19	28.01	1930.3	13.5	52400.	8042.	.00697
			4	103.98	28.30	1926.2	17.7	52167.	10486.	.00908
			5	103.36	29.50	1920.5	23.4	51653.	13912.	.01203
			6	103.08	30.01	1915.9	28.0	51376.	16676.	.01441
			7	102.90	30.32	1911.5	32.4	51160.	19305.	.01667
			8	102.65	30.78	1906.6	37.3	50889.	22212.	.01916
			9	101.55	32.75	1898.6	45.3	50077.	27095.	.02331
RUN 6	90.	118.75								
			1	104.38	25.87	2080.1	0.7	56584.	402.	.00033
			2	104.15	26.28	2076.6	4.2	56345.	2471.	.00200
			3	104.19	26.21	2074.1	6.7	56301.	3987.	.00323
			4	103.95	26.64	2070.3	10.5	56050.	6231.	.00504
			5	103.27	27.86	2064.7	16.1	55485.	9569.	.00773
			6	102.92	28.49	2060.2	20.5	55150.	12232.	.00987
			7	102.69	28.91	2056.1	24.6	54903.	14683.	.01184
			8	102.38	29.46	2051.6	29.1	54601.	17384.	.01400
			9	101.29	31.42	2044.0	36.8	53762.	22014.	.01768

S	T_s	i	T_{bi}	ΔT_{ov}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 7 93.	118.40								
		1	105.27	23.63	2033.2	1.5	55860.	890.	.00074
		2	104.47	25.07	2027.5	7.2	55209.	4251.	.00352
		3	104.06	25.79	2023.3	11.4	54853.	6779.	.00561
		4	103.81	26.25	2019.4	15.3	54591.	9032.	.00751
		5	103.23	27.31	2014.2	20.5	54101.	12215.	.01008
		6	102.69	27.92	2009.7	25.0	53781.	14866.	.01226
		7	102.58	28.47	2005.3	29.4	53484.	17526.	.01444
		8	102.33	28.93	2000.9	33.8	53220.	20153.	.01660
		9	101.25	30.86	1993.3	41.4	52407.	24760.	.02033
RUN 8 47.	123.80								
		1	103.63	36.30	896.2	1.8	24180.	1079.	.00202
		2	102.92	37.59	891.4	6.7	23860.	3964.	.00741
		3	102.69	38.00	887.3	10.8	23692.	6424.	.01200
		4	102.77	37.85	883.5	14.5	23613.	8646.	.01615
		5	102.30	38.70	878.8	19.3	23365.	11509.	.02147
		6	102.08	39.10	874.3	23.8	23190.	14199.	.02648
		7	102.28	38.73	870.3	27.7	23138.	16534.	.03085
		8	102.42	38.49	866.2	31.9	23059.	19015.	.03549
		9	101.43	40.26	860.1	38.0	22656.	22705.	.04226
RUN 9 51.	123.95								
		1	102.57	38.48	904.1	1.3	24109.	764.	.00142
		2	102.14	39.26	899.7	5.6	23882.	3354.	.00620
		3	101.82	39.83	895.4	9.9	23687.	5935.	.01097
		4	101.86	39.76	891.6	13.8	23594.	8238.	.01523
		5	101.53	40.36	887.0	18.4	23389.	10999.	.02031
		6	101.38	40.63	882.5	22.8	23234.	13655.	.02521
		7	101.54	40.35	878.5	26.9	23166.	16072.	.02968
		8	101.62	40.19	874.2	31.2	23074.	18638.	.03443
		9	100.67	41.90	868.1	37.3	22682.	22357.	.04119

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{li}	W_{gi}	Re_{li}	Re_{gi}	x_{bi}
RUN 10	60.	124.50								
			1	103.72	37.40	1140.9	1.8	30812.	1075.	.00158
			2	102.92	38.84	1135.4	7.3	30396.	4357.	.00640
			3	102.57	39.47	1130.8	11.9	30155.	7125.	.01045
			4	102.52	39.56	1126.7	16.0	30032.	9548.	.01401
			5	101.97	40.55	1121.5	21.3	29714.	12705.	.01861
			6	101.77	40.91	1116.8	25.9	29527.	15497.	.02269
			7	101.68	40.71	1112.6	30.1	29452.	17983.	.02634
			8	101.90	40.67	1108.1	34.6	29338.	20694.	.03031
			9	100.89	42.49	1101.2	41.5	28840.	24894.	.03636
RUN 11	62.	124.45								
			1	103.12	38.39	1256.4	0.4	33708.	248.	.00033
			2	103.24	38.18	1253.1	3.7	33661.	2227.	.00298
			3	103.14	38.35	1249.1	7.7	33518.	4614.	.00617
			4	103.05	38.51	1244.9	11.9	33374.	7098.	.00948
			5	102.67	39.20	1239.9	17.0	33101.	10108.	.01349
			6	102.51	39.48	1235.2	21.7	32918.	12918.	.01723
			7	102.46	39.59	1230.5	26.3	32773.	15695.	.02093
			8	102.41	39.68	1225.7	31.1	32627.	18567.	.02476
			9	101.46	41.38	1218.6	38.2	32109.	22847.	.03039
RUN 12	72.	123.55								
			1	103.28	36.49	1415.6	1.2	38044.	723.	.00086
			2	103.04	36.92	1411.3	5.5	37830.	3253.	.00386
			3	102.98	37.02	1407.4	9.4	37703.	5578.	.00661
			4	102.74	37.46	1402.9	13.9	37481.	8292.	.00982
			5	102.13	38.56	1397.2	19.6	37083.	11683.	.01381
			6	102.00	38.80	1392.7	24.1	36909.	14389.	.01700
			7	101.98	38.87	1388.4	28.5	36789.	16909.	.02009
			8	101.80	39.14	1383.3	33.5	36585.	20003.	.02362
			9	100.72	41.09	1375.8	41.0	35967.	24574.	.02893

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 13	78.	124.20								
			1	104.39	35.66	1606.8	1.0	43713.	590.	.00062
			2	104.08	36.21	1602.3	5.4	43445.	3236.	.00339
			3	103.98	36.40	1598.3	9.5	43285.	5637.	.00590
			4	103.71	36.89	1593.6	14.2	43027.	8449.	.00884
			5	103.00	38.16	1587.4	20.4	42529.	12163.	.01270
			6	102.82	38.48	1582.5	25.2	42317.	15034.	.01569
			7	102.84	38.44	1578.2	29.6	42211.	17640.	.01841
			8	102.55	38.97	1572.7	35.1	41929.	20938.	.02184
			9	101.33	41.16	1564.3	43.5	41161.	26043.	.02707
RUN 14	88.	123.75								
			1	104.71	34.28	1921.7	1.1	52465.	676.	.00059
			2	104.39	34.84	1917.1	5.8	52158.	3445.	.00302
			3	104.34	34.94	1913.1	9.7	52019.	5769.	.00506
			4	104.09	35.38	1908.4	14.5	51749.	8609.	.00754
			5	103.42	36.59	1901.9	21.0	51193.	12491.	.01092
			6	103.17	37.04	1896.7	26.2	50911.	15595.	.01362
			7	103.02	37.31	1891.7	31.2	50696.	18585.	.01623
			8	102.86	37.59	1886.4	36.5	50467.	21727.	.01896
			9	101.70	39.69	1877.4	45.5	49595.	27203.	.02366
RUN 15	90.	125.35								
			1	104.42	37.66	1901.6	1.0	51753.	617.	.00055
			2	104.30	37.89	1897.3	5.3	51566.	3128.	.00277
			3	104.37	37.77	1893.6	9.0	51501.	5353.	.00474
			4	104.10	38.25	1888.5	14.1	51212.	8394.	.00743
			5	103.40	39.51	1881.6	21.0	50634.	12490.	.01103
			6	103.08	40.09	1875.9	26.7	50304.	15889.	.01402
			7	102.92	40.37	1870.6	32.0	50074.	19064.	.01682
			8	102.71	40.75	1864.9	37.7	49808.	22466.	.01981
			9	101.50	42.92	1855.5	47.1	48915.	28155.	.02474

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 16	61.	128.85								
			1	104.16	44.44	1098.4	2.1	29805.	1238.	.00189
			2	103.52	45.58	1092.5	8.0	29438.	4749.	.00726
			3	103.23	46.12	1087.1	13.4	29199.	7958.	.01215
			4	103.20	46.17	1082.0	18.4	29054.	10949.	.01671
			5	102.80	46.88	1076.1	24.3	28770.	14510.	.02212
			6	102.60	47.25	1070.4	30.1	28553.	17940.	.02734
			7	102.66	47.14	1065.0	35.5	28427.	21150.	.03224
			8	102.71	47.06	1059.4	41.1	28292.	24486.	.03733
			9	101.60	49.04	1051.3	49.1	27744.	29391.	.04466
RUN 17	64.	130.90								
			1	104.26	47.95	1159.2	2.2	31492.	1286.	.00186
			2	103.71	48.94	1153.1	8.3	31135.	4948.	.00717
			3	103.50	49.33	1147.5	13.9	30912.	8262.	.01196
			4	103.39	49.52	1142.1	19.4	30729.	11515.	.01666
			5	102.95	50.31	1135.7	25.7	30412.	15310.	.02213
			6	103.01	50.20	1130.3	31.1	30286.	18543.	.02680
			7	103.09	50.06	1124.7	36.7	30163.	21859.	.03161
			8	102.95	50.32	1118.4	43.0	29948.	25596.	.03699
			9	101.77	52.43	1109.8	51.6	29340.	30850.	.04444
RUN 18	73.	129.50								
			1	104.36	45.24	1359.9	1.5	36986.	878.	.00109
			2	104.10	45.71	1354.5	6.9	36734.	4068.	.00503
			3	104.01	45.88	1349.3	12.1	36554.	7174.	.00887
			4	103.92	46.04	1343.8	17.5	36370.	10417.	.01288
			5	103.37	47.03	1337.0	24.4	35966.	14509.	.01791
			6	103.24	47.27	1331.0	30.4	35754.	18081.	.02231
			7	103.26	47.22	1325.2	36.2	35607.	21537.	.02658
			8	102.98	47.74	1318.4	42.9	35315.	25582.	.03155
			9	101.74	49.96	1309.1	52.2	34600.	31229.	.03838

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 19	75.	129.60								
			1	104.41	45.34	1358.5	1.3	36967.	782.	.00097
			2	104.41	45.35	1353.9	5.9	36840.	3510.	.00435
			3	104.33	45.49	1348.9	10.9	36671.	6483.	.00803
			4	104.03	46.03	1343.1	16.7	36396.	9907.	.01227
			5	103.46	47.05	1336.5	23.3	35988.	13885.	.01716
			6	103.24	47.45	1330.5	29.3	35741.	17451.	.02156
			7	103.27	47.39	1324.9	34.9	35603.	20764.	.02565
			8	103.11	47.68	1318.7	41.1	35373.	24496.	.03025
			9	101.79	50.06	1309.3	50.5	34623.	30171.	.03712
RUN 20	90.	129.40								
			1	106.42	41.37	1651.3	3.1	45956.	1854.	.00190
			2	105.36	43.27	1643.3	11.1	45193.	6583.	.00672
			3	105.05	43.83	1637.5	16.9	44877.	10031.	.01024
			4	104.97	43.97	1632.3	22.2	44697.	13128.	.01340
			5	104.40	45.00	1625.3	29.1	44223.	17255.	.01758
			6	104.06	45.61	1619.0	35.4	43885.	21034.	.02141
			7	104.00	45.72	1613.3	41.1	43702.	24410.	.02484
			8	103.83	46.03	1607.1	47.4	43451.	28144.	.02863
			9	102.46	48.49	1596.9	57.6	42533.	34334.	.03479
RUN 21	97.	129.50								
			1	106.56	41.29	1757.6	3.1	48996.	1836.	.00177
			2	105.60	43.02	1749.4	11.3	48242.	6663.	.00640
			3	105.32	43.52	1743.4	17.3	47924.	10260.	.00985
			4	105.24	43.67	1737.8	22.9	47728.	13564.	.01301
			5	104.56	44.88	1730.1	30.6	47159.	18163.	.01739
			6	104.30	45.36	1723.5	37.2	46843.	22060.	.02111
			7	104.21	45.53	1717.3	43.4	46625.	25740.	.02463
			8	103.86	46.15	1710.1	50.6	46253.	30058.	.02873
			9	102.41	48.76	1699.1	61.6	45231.	36762.	.03499

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 22	38.	133.35								
			1	102.69	54.82	518.9	2.7	13886.	1586.	.00510
			2	102.24	56.00	512.8	8.7	13627.	5195.	.01669
			3	102.10	56.25	507.2	14.3	13457.	8561.	.02749
			4	102.18	56.10	501.7	19.9	13323.	11860.	.03809
			5	101.85	56.70	495.6	25.9	13114.	15492.	.04971
			6	101.83	56.73	489.8	31.8	12957.	19000.	.06096
			7	102.07	56.30	483.9	37.6	12835.	22466.	.07213
			8	102.20	56.07	477.8	43.8	12690.	26132.	.08393
			9	101.20	57.87	470.4	51.2	12359.	30651.	.09817
RUN 23	53.	133.30								
			1	103.91	52.90	852.8	2.4	23078.	1404.	.00276
			2	103.29	54.02	846.6	8.6	22754.	5115.	.01005
			3	103.10	54.35	840.9	14.3	22555.	8512.	.01671
			4	103.11	54.34	835.3	19.8	22407.	11816.	.02320
			5	102.57	55.31	828.7	26.4	22100.	15761.	.03090
			6	102.46	55.50	822.7	32.5	21913.	19394.	.03802
			7	102.74	55.01	817.0	38.2	21827.	22768.	.04466
			8	102.67	54.77	810.9	44.3	21695.	26406.	.05182
			9	101.72	56.84	802.5	52.7	21206.	31479.	.06158
RUN 24	65.	132.70								
			1	103.67	52.24	1078.4	1.0	29108.	620.	.00097
			2	103.67	52.25	1073.1	6.4	28963.	3783.	.00589
			3	103.41	52.72	1066.9	12.6	28713.	7472.	.01163
			4	103.43	52.69	1061.1	18.4	28563.	10935.	.01703
			5	102.92	53.61	1054.0	25.4	28213.	15159.	.02357
			6	102.68	54.03	1047.4	32.1	27966.	19122.	.02971
			7	102.75	53.92	1041.2	38.3	27818.	22826.	.03547
			8	102.61	54.16	1034.4	45.1	27595.	26897.	.04179
			9	101.37	56.40	1025.1	54.4	26982.	32555.	.05040

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 25	67.	133.00								
			1	104.05	52.11	1124.2	1.2	30470.	727.	.00109
			2	103.66	52.82	1119.0	6.4	30198.	3809.	.00569
			3	103.33	53.41	1113.8	11.6	29948.	6920.	.01033
			4	103.31	53.44	1109.1	16.3	29817.	9729.	.01452
			5	102.88	54.22	1103.3	22.1	29523.	13172.	.01964
			6	102.75	54.46	1098.0	27.4	29337.	16338.	.02435
			7	102.78	54.40	1092.9	32.5	29212.	19386.	.02890
			8	102.68	54.58	1087.4	38.1	29032.	22704.	.03384
			9	101.50	56.69	1079.4	46.0	28456.	27523.	.04088
RUN 26	71.	133.35								
			1	104.75	51.49	1222.6	2.2	33392.	1297.	.00179
			2	104.29	52.31	1216.1	8.6	33048.	5127.	.00705
			3	104.24	52.40	1210.4	14.3	32875.	8518.	.01172
			4	104.22	52.43	1204.6	20.2	32712.	11964.	.01646
			5	103.67	53.42	1197.4	27.4	32317.	16271.	.02235
			6	103.43	53.86	1190.7	34.0	32053.	20253.	.02779
			7	103.41	53.89	1184.3	40.4	31874.	24053.	.03301
			8	103.40	53.91	1177.8	47.0	31693.	27962.	.03837
			9	102.13	56.19	1168.1	56.6	31004.	33804.	.04622
RUN 27	88.	133.35								
			1	105.50	50.14	1422.6	2.8	39183.	1643.	.00195
			2	104.66	51.64	1414.8	10.6	38607.	6261.	.00741
			3	104.52	51.89	1408.6	16.7	38378.	9926.	.01174
			4	104.45	52.03	1402.4	22.9	38178.	13604.	.01609
			5	103.75	53.28	1394.4	31.0	37668.	18412.	.02173
			6	103.59	53.57	1387.6	37.8	37413.	22470.	.02651
			7	103.43	53.85	1380.6	44.8	37166.	26641.	.03142
			8	103.27	54.13	1373.3	52.0	36906.	30978.	.03651
			9	101.94	56.54	1362.8	62.6	36094.	37402.	.04392

S	Ts	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 28 37.	139.45								
		1	102.56	65.67	462.7	3.1	12392.	1850.	.00667
		2	102.55	66.41	455.7	10.0	12152.	5989.	.02156
		3	102.45	66.61	449.0	16.8	11957.	10016.	.03605
		4	102.44	66.62	442.3	23.5	11777.	14041.	.05053
		5	102.09	67.24	435.1	30.7	11543.	18327.	.06589
		6	102.15	67.14	428.1	37.6	11365.	22479.	.08083
		7	102.31	66.84	421.1	44.7	11198.	26677.	.09597
		8	102.38	66.73	413.7	52.1	11010.	31063.	.11176
		9	101.40	68.48	405.3	60.5	10672.	36215.	.12995
RUN 29 45.	139.83								
		1	103.48	65.42	586.4	3.1	15795.	1873.	.00534
		2	102.50	66.47	579.3	10.2	15504.	6100.	.01736
		3	102.76	66.72	572.6	17.0	15301.	10131.	.02883
		4	102.87	66.53	565.9	23.7	15140.	14110.	.04017
		5	102.54	67.13	558.5	31.0	14888.	18517.	.05266
		6	102.43	67.31	551.2	38.4	14677.	22887.	.06507
		7	102.47	67.24	543.8	45.7	14487.	27279.	.07757
		8	102.68	66.86	536.4	53.1	14323.	31672.	.09011
		9	101.73	68.58	527.6	61.9	13943.	37025.	.10506
RUN 30 66.	139.80								
		1	103.75	64.89	585.8	3.3	15825.	1940.	.00554
		2	103.12	66.03	578.5	10.6	15518.	6313.	.01800
		3	103.00	66.24	571.6	17.5	15314.	10417.	.02969
		4	102.97	66.29	564.7	24.4	15124.	14537.	.04143
		5	102.55	67.04	557.2	31.9	14856.	19016.	.05413
		6	102.62	66.92	550.1	39.0	14677.	23257.	.06621
		7	102.67	66.83	542.7	46.3	14489.	27620.	.07864
		8	102.62	66.92	535.1	54.0	14278.	32170.	.09159
		9	101.70	68.58	526.3	62.7	13904.	37496.	.10648

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 31	51.	139.70								
			1	103.91	64.42	696.4	3.0	18845.	1765.	.00425
			2	103.49	65.18	689.2	10.2	18564.	6050.	.01454
			3	103.48	65.10	682.4	16.9	18381.	10068.	.02420
			4	103.02	64.93	675.7	23.6	18229.	14047.	.03378
			5	103.05	65.97	667.9	31.4	17906.	18710.	.04492
			6	102.83	66.37	660.4	38.9	17662.	23192.	.05565
			7	103.04	65.98	653.3	46.1	17512.	27440.	.06588
			8	103.10	65.87	645.7	53.6	17321.	31930.	.07667
			9	101.92	68.00	636.4	63.0	16852.	37619.	.09003
RUN 32	64.	139.70								
			1	103.75	64.70	905.0	2.2	24448.	1288.	.00239
			2	103.62	64.95	898.3	8.8	24231.	5231.	.00970
			3	103.37	65.46	891.2	15.9	23974.	9457.	.01752
			4	103.36	65.41	884.3	22.8	23786.	13576.	.02515
			5	102.98	66.10	876.5	30.6	23478.	18249.	.03377
			6	102.75	66.51	868.7	38.5	23210.	22927.	.04240
			7	102.75	66.52	861.0	46.2	23003.	27526.	.05091
			8	102.87	66.28	853.2	53.9	22828.	32138.	.05946
			9	101.72	68.35	843.1	64.0	22278.	38284.	.07060
RUN 33	69.	139.15								
			1	104.92	61.60	1005.4	3.5	27517.	2051.	.00343
			2	104.13	63.04	997.3	11.6	27053.	6917.	.01155
			3	104.08	63.13	990.3	18.6	26849.	11025.	.01840
			4	104.11	63.07	983.5	25.5	26673.	15113.	.02523
			5	103.47	64.22	975.2	33.8	26263.	20081.	.03346
			6	103.35	64.44	967.6	41.3	26024.	24579.	.04094
			7	103.36	64.42	960.1	48.8	25824.	29060.	.04841
			8	103.20	64.71	951.9	57.0	25561.	33910.	.05646
			9	101.86	67.09	941.4	67.5	24917.	40343.	.06692

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 34	71.	140.50								
			1	104.40	64.98	996.7	2.8	27119.	1662.	.00280
			2	103.93	65.82	989.2	10.3	26776.	6134.	.01033
			3	103.80	66.05	982.0	17.5	26544.	10394.	.01750
			4	103.79	66.08	974.8	24.7	26344.	14681.	.02471
			5	103.22	67.10	966.3	33.2	25952.	19769.	.03323
			6	102.92	67.63	958.0	41.5	25647.	24700.	.04148
			7	103.01	67.48	950.2	49.3	25462.	29349.	.04930
			8	102.97	67.55	941.9	57.5	25230.	34281.	.05758
			9	101.59	70.03	931.0	68.5	24566.	40983.	.06857
RUN 35	73.	138.00								
			1	103.65	61.82	1081.3	1.4	29179.	823.	.00128
			2	103.60	61.92	1075.5	7.2	29006.	4254.	.00661
			3	103.57	61.97	1069.6	13.1	28836.	7793.	.01210
			4	103.70	61.75	1063.7	19.0	28717.	11267.	.01750
			5	103.01	62.98	1056.0	26.7	28296.	15875.	.02462
			6	102.77	63.41	1049.0	33.7	28035.	20066.	.03110
			7	102.86	63.26	1042.4	40.2	27888.	23970.	.03716
			8	102.78	63.40	1035.3	47.4	27672.	28227.	.04374
			9	101.43	65.82	1025.5	57.2	27013.	34214.	.05282
RUN 36	75.	138.70								
			1	105.03	60.61	1090.4	2.5	29876.	1471.	.00227
			2	104.53	61.51	1082.6	10.2	29500.	6054.	.00934
			3	104.23	62.05	1075.1	17.7	29198.	10515.	.01621
			4	104.29	61.95	1068.2	24.7	29027.	14643.	.02258
			5	103.75	62.91	1059.8	33.0	28630.	19619.	.03020
			6	103.52	63.32	1052.0	40.9	28346.	24322.	.03742
			7	103.50	63.35	1044.3	48.5	28135.	28877.	.04442
			8	103.58	63.22	1036.6	56.2	27949.	33436.	.05145
			9	102.29	65.54	1026.1	66.8	27280.	39846.	.06109

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 37	79.	139.60								
			1	105.64	61.12	1133.8	3.7	31280.	2188.	.00325
			2	104.75	62.74	1125.2	12.3	30732.	7290.	.01081
			3	104.69	62.84	1118.1	19.3	30521.	11458.	.01699
			4	104.71	62.81	1111.0	26.4	30333.	15663.	.02323
			5	104.04	64.00	1102.3	35.2	29875.	20882.	.03091
			6	103.76	64.51	1094.1	43.3	29560.	25755.	.03809
			7	103.63	64.74	1086.1	51.4	29301.	30571.	.04520
			8	103.65	64.70	1078.0	59.4	29091.	35332.	.05224
			9	102.38	66.99	1067.2	70.3	28401.	41946.	.06180
RUN 38	84.	139.78								
			1	104.52	63.46	1257.3	1.3	34256.	761.	.00102
			2	104.73	63.08	1251.3	7.3	34173.	4312.	.00578
			3	104.74	63.07	1244.6	14.0	33991.	8293.	.01112
			4	104.83	62.91	1237.8	20.7	33841.	12283.	.01647
			5	104.16	64.12	1229.1	29.5	33353.	17499.	.02342
			6	103.81	64.75	1220.9	37.7	33002.	22403.	.02995
			7	103.88	64.62	1213.4	45.2	32825.	26841.	.03589
			8	103.77	64.82	1205.3	53.3	32566.	31668.	.04233
			9	102.30	67.45	1193.8	64.7	31745.	38619.	.05141
RUN 39	85.	139.30								
			1	105.87	60.17	1159.5	3.5	32074.	2073.	.00302
			2	105.08	61.59	1151.0	12.0	31558.	7094.	.01030
			3	104.96	61.82	1143.8	19.2	31313.	11403.	.01655
			4	104.92	61.88	1136.5	26.5	31104.	15716.	.02281
			5	104.21	63.17	1127.5	35.5	30612.	21088.	.03054
			6	103.94	63.65	1119.3	43.6	30299.	25995.	.03762
			7	103.92	63.68	1111.4	51.7	30080.	30702.	.04443
			8	103.82	63.86	1103.0	60.0	29822.	35654.	.05159
			9	102.41	66.40	1091.7	71.3	29063.	42542.	.06131

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 40	86.	139.55								
			1	105.14	61.96	1278.1	2.4	35063.	1434.	.00189
			2	104.88	62.41	1270.8	9.7	34761.	5763.	.00760
			3	104.80	62.55	1263.7	16.8	34536.	9967.	.01313
			4	104.77	62.60	1256.5	24.0	34329.	14213.	.01873
			5	104.04	63.97	1247.5	33.0	33808.	19601.	.02577
			6	103.67	64.58	1239.1	41.4	33446.	24585.	.03229
			7	103.68	64.56	1231.5	49.0	33243.	29141.	.03828
			8	103.65	64.62	1223.5	57.0	33016.	33877.	.04450
			9	102.21	67.21	1212.1	68.4	32197.	40836.	.05342
RUN 41	95.	139.73								
			1	106.14	60.46	1329.8	3.7	36893.	2170.	.00276
			2	105.26	62.04	1321.0	12.4	36291.	7360.	.00933
			3	105.18	62.18	1314.0	19.5	36065.	11532.	.01461
			4	105.00	62.51	1306.4	27.0	35783.	16017.	.02028
			5	104.22	63.92	1297.1	36.3	35221.	21578.	.02726
			6	104.00	64.31	1288.9	44.5	34914.	26449.	.03339
			7	103.92	64.47	1280.8	52.6	34662.	31278.	.03948
			8	103.84	64.60	1272.4	61.0	34407.	36255.	.04575
			9	102.28	67.41	1260.2	73.2	33500.	43711.	.05492
RUN 42	33.	143.80								
			1	103.23	73.02	380.9	3.6	10230.	2117.	.00925
			2	102.61	74.14	373.1	11.3	9954.	6738.	.02940
			3	102.25	74.79	365.4	19.0	9711.	11328.	.04937
			4	102.22	74.84	357.9	26.6	9507.	15850.	.06907
			5	102.00	75.26	350.0	34.4	9275.	20564.	.08956
			6	101.56	75.32	342.1	42.4	9061.	25301.	.11017
			7	101.54	75.34	333.9	50.5	8845.	30152.	.13129
			8	102.21	74.85	325.8	58.6	8654.	35009.	.15256
			9	101.50	76.15	316.7	67.7	8347.	40513.	.17618

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 43	42.	143.95								
			1	103.77	72.31	494.2	3.5	13354.	2057.	.00696
			2	103.32	73.13	486.5	11.2	13080.	6642.	.02243
			3	103.18	73.39	478.9	18.7	12857.	11142.	.03761
			4	103.22	73.30	471.4	26.2	12662.	15617.	.05272
			5	102.63	74.02	463.3	34.3	12391.	20447.	.06895
			6	102.58	74.46	455.2	42.4	12142.	25298.	.08524
			7	102.64	74.35	447.2	50.5	11935.	30083.	.10138
			8	102.97	73.76	439.2	58.5	11763.	34822.	.11746
			9	102.12	75.29	430.0	67.7	11410.	40417.	.13601
RUN 44	45.	143.85								
			1	103.87	71.95	523.1	3.8	14151.	2265.	.00723
			2	103.13	73.30	514.9	12.1	13814.	7186.	.02290
			3	103.04	73.46	507.2	19.8	13594.	11769.	.03750
			4	103.17	73.23	499.6	27.3	13410.	16263.	.05184
			5	102.75	73.97	491.4	35.5	13131.	21168.	.06739
			6	102.69	74.08	483.4	43.5	12908.	25960.	.08264
			7	102.81	73.86	475.3	51.6	12709.	30763.	.09796
			8	102.88	73.74	466.9	60.0	12495.	35746.	.11385
			9	101.89	75.52	457.3	69.6	12106.	41609.	.13216
RUN 45	48.	143.90								
			1	103.87	72.05	584.8	3.5	15821.	2061.	.00590
			2	103.33	73.03	576.9	11.4	15512.	6788.	.01939
			3	103.31	73.05	569.4	18.9	15309.	11248.	.03213
			4	103.58	72.58	562.1	26.2	15155.	15609.	.04462
			5	103.10	73.43	553.7	34.6	14853.	20586.	.05876
			6	102.84	73.90	545.4	42.9	14589.	25560.	.07291
			7	103.01	73.60	537.3	51.0	14397.	30397.	.08674
			8	103.10	73.43	528.8	59.5	14184.	35439.	.10116
			9	102.00	75.41	518.8	69.5	13750.	41537.	.11820

	S	T_S	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 46	52.	143.85								
			1	104.17	71.43	641.2	3.4	17400.	2038.	.00533
			2	103.51	72.60	633.1	11.5	17058.	6852.	.01787
			3	103.38	72.84	625.5	19.2	16829.	11396.	.02971
			4	103.52	72.58	618.0	26.6	16653.	15843.	.04132
			5	103.62	73.48	609.6	35.1	16336.	20889.	.05441
			6	102.87	73.76	601.3	43.3	16088.	25804.	.06718
			7	102.82	73.85	593.0	51.6	15856.	30781.	.08012
			8	102.81	73.86	584.4	60.2	15626.	35882.	.09340
			9	101.85	75.59	574.5	70.1	15202.	41911.	.10880
RUN 47	58.	143.40								
			1	104.08	70.78	714.4	3.6	19368.	2147.	.00504
			2	103.38	72.05	706.1	11.9	18996.	7067.	.01654
			3	103.29	72.19	698.5	19.5	18775.	11608.	.02716
			4	103.27	72.23	690.8	27.2	18563.	16213.	.03794
			5	102.64	73.37	682.0	36.0	18200.	21469.	.05015
			6	102.45	73.72	673.6	44.4	17938.	26498.	.06186
			7	102.71	73.25	665.5	52.5	17773.	31301.	.07313
			8	102.51	72.88	657.1	60.9	17587.	36304.	.08487
			9	101.66	75.14	646.5	71.5	17072.	42721.	.09951
RUN 48	70.	143.90								
			1	104.42	71.07	906.6	2.8	24671.	1642.	.00304
			2	104.12	71.61	898.6	10.7	24374.	6349.	.01176
			3	103.97	71.87	890.8	18.6	24123.	11025.	.02041
			4	104.08	71.68	883.1	26.2	23943.	15573.	.02884
			5	103.46	72.79	874.0	35.3	23535.	21023.	.03886
			6	103.17	73.31	865.2	44.1	23224.	26279.	.04854
			7	103.24	73.19	856.7	52.6	23014.	31310.	.05784
			8	103.20	73.26	847.8	61.5	22765.	36617.	.06764
			9	101.89	75.61	836.6	72.8	22146.	43483.	.08003

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	x_{bi}
RUN 49	71.	143.50								
			1	104.54	70.13	945.1	2.8	25756.	1633.	.00290
			2	104.28	70.60	937.3	10.6	25468.	6289.	.01118
			3	104.23	70.68	929.7	18.2	25248.	10817.	.01923
			4	104.37	70.42	922.2	25.7	25084.	15247.	.02711
			5	103.63	71.77	912.9	34.9	24629.	20774.	.03686
			6	103.16	72.61	903.9	43.9	24261.	26165.	.04636
			7	103.26	72.42	895.6	52.2	24066.	31088.	.05510
			8	103.30	72.36	886.9	60.9	23842.	36262.	.06428
			9	101.57	74.75	875.6	72.3	23198.	43180.	.07626
RUN 50	74.	144.75								
			1	105.08	71.41	925.6	3.5	25375.	2088.	.00380
			2	104.51	72.42	917.0	12.2	24982.	7216.	.01309
			3	104.37	72.67	908.8	20.4	24720.	12090.	.02193
			4	104.36	72.70	900.5	28.6	24491.	16981.	.03080
			5	103.73	73.83	891.0	38.1	24066.	22664.	.04104
			6	103.48	74.29	882.0	47.2	23754.	28069.	.05078
			7	103.54	74.18	873.3	55.9	23535.	33244.	.06016
			8	103.62	74.03	864.4	64.8	23318.	38507.	.06970
			9	102.25	76.51	852.9	76.3	22664.	45520.	.08207
RUN 51	85.	144.05								
			1	105.08	70.14	1097.7	2.7	30095.	1607.	.00247
			2	104.83	70.60	1089.5	10.9	29786.	6447.	.00989
			3	104.62	70.97	1081.2	19.2	29489.	11397.	.01747
			4	104.01	70.99	1073.0	27.4	29263.	16245.	.02490
			5	104.05	72.00	1063.5	36.9	28823.	21936.	.03357
			6	103.75	72.54	1054.2	46.2	28479.	27435.	.04194
			7	103.71	72.61	1045.3	55.1	28226.	32741.	.05005
			8	103.60	72.81	1036.1	64.3	27942.	38254.	.05846
			9	102.15	75.47	1024.0	76.4	27183.	45624.	.06944

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 52	92.	143.68								
			1	106.08	67.67	1181.6	3.6	32762.	2130.	.00304
			2	105.36	68.97	1172.5	12.7	32247.	7528.	.01073
			3	105.20	69.26	1164.4	20.8	31964.	12334.	.01758
			4	105.06	69.52	1156.1	29.1	31687.	17242.	.02456
			5	104.37	70.75	1146.4	38.8	31183.	23038.	.03276
			6	104.09	71.25	1137.3	47.9	30841.	28418.	.04038
			7	104.03	71.37	1128.5	56.6	30581.	33645.	.04780
			8	104.06	71.31	1119.7	65.5	30354.	38873.	.05523
			9	102.46	74.20	1107.2	78.0	29491.	46525.	.06580
RUN 53	96.	143.65								
			1	106.10	67.58	1230.1	3.7	34114.	2202.	.00302
			2	105.36	68.91	1220.7	13.1	33573.	7762.	.01063
			3	105.18	69.24	1212.4	21.4	33277.	12693.	.01738
			4	105.14	69.32	1204.1	29.7	33034.	17564.	.02404
			5	104.53	70.42	1194.4	39.4	32545.	23377.	.03195
			6	104.21	70.98	1185.1	48.7	32179.	28919.	.03948
			7	104.06	71.25	1175.9	57.9	31877.	34374.	.04691
			8	103.98	71.41	1166.7	67.1	31596.	39874.	.05441
			9	102.37	74.30	1153.8	80.0	30704.	47726.	.06483
RUN 54	27.	149.10								
			1	102.68	83.56	286.8	4.0	7656.	2372.	.01369
			2	102.08	84.63	278.3	12.4	7383.	7416.	.04271
			3	101.79	85.15	270.0	20.8	7139.	12410.	.07142
			4	101.90	84.96	261.7	29.0	6929.	17328.	.09975
			5	101.66	85.03	253.3	37.5	6702.	22393.	.12889
			6	101.75	85.24	244.6	46.2	6464.	27602.	.15882
			7	101.59	85.51	235.6	55.2	6216.	32983.	.18971
			8	101.93	84.90	226.5	64.2	5999.	38368.	.22089
			9	101.20	86.22	216.6	74.1	5691.	44379.	.25497

	S	Ts	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 55	39.	147.80								
			1	102.84	80.92	427.5	3.6	11433.	2161.	.00841
			2	102.78	81.03	419.5	11.6	11212.	6933.	.02698
			3	102.70	81.18	411.3	19.8	10984.	11792.	.04588
			4	102.62	81.32	403.0	28.1	10754.	16727.	.06507
			5	102.21	82.07	394.3	36.8	10474.	21949.	.08529
			6	101.96	82.51	385.5	45.5	10213.	27211.	.10566
			7	102.00	82.45	376.7	54.4	9983.	32483.	.12615
			8	102.31	81.87	367.8	63.3	9781.	37772.	.14682
			9	101.45	83.43	357.7	73.4	9424.	43896.	.17021
RUN 56	48.	148.00								
			1	102.03	82.75	515.3	3.1	13661.	1824.	.00589
			2	102.46	81.96	507.5	10.9	13518.	6488.	.02098
			3	102.42	82.04	499.1	19.3	13287.	11512.	.03722
			4	102.62	81.68	490.8	27.6	13094.	16472.	.05329
			5	102.33	82.20	481.8	36.6	12816.	21825.	.07055
			6	102.13	82.57	472.8	45.6	12547.	27229.	.08797
			7	102.16	82.48	463.8	54.6	12315.	32595.	.10532
			8	102.44	82.01	454.8	63.6	12110.	37949.	.12271
			9	101.41	83.86	444.3	74.0	11702.	44298.	.14283
RUN 57	55.	146.90								
			1	104.49	76.35	624.5	4.0	17008.	2394.	.00642
			2	103.88	77.43	615.6	12.9	16656.	7657.	.02050
			3	103.81	77.56	607.2	21.3	16414.	12668.	.03391
			4	103.87	77.46	598.8	29.8	16195.	17694.	.04738
			5	103.33	78.43	589.4	39.1	15847.	23297.	.06228
			6	102.98	79.06	580.0	48.5	15536.	28913.	.07722
			7	102.99	79.04	570.7	57.8	15290.	34425.	.09195
			8	103.21	78.63	561.4	67.1	15078.	39935.	.10673
			9	102.13	80.60	550.4	78.1	14608.	46633.	.12425

	S	Ts	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 58	57.	148.20								
			1	104.00	79.55	636.5	4,2	17244.	2597.	.00659
			2	103.25	80.90	627.4	13,4	16856.	7967.	.02089
			3	103.23	80.95	618.9	21,8	16624.	13002.	.03409
			4	103.34	80.74	610.4	30,3	16417.	18045.	.04732
			5	102.92	81.50	601.1	39,7	16090.	23639.	.06192
			6	102.87	81.59	591.9	48,8	15836.	29103.	.07622
			7	102.75	81.82	582.4	58.4	15561.	34786.	.09108
			8	102.75	81.82	572.8	68,0	15303.	40530.	.10612
			9	101.66	83.77	561.7	79,1	14831.	47287.	.12343
RUN 59	61.	148.90								
			1	103.97	80.87	665.0	3,8	18008.	2257.	.00568
			2	103.81	81.16	656.4	12,4	17743.	7395.	.01860
			3	103.72	81.32	647.6	21,2	17490.	12584.	.03165
			4	103.64	81.46	638.7	30,1	17235.	17878.	.04496
			5	103.14	82.37	629.1	39,7	16882.	23629.	.05934
			6	102.91	82.78	619.7	49,1	16586.	29279.	.07348
			7	102.91	82.79	610.3	58,5	16334.	34884.	.08754
			8	102.91	82.79	600.6	68,2	16075.	40634.	.10197
			9	101.76	84.85	589.4	79,4	15581.	47451.	.11870
RUN 60	61.	148.00								
			1	103.52	80.06	678.5	3,2	18282.	1914.	.00472
			2	103.46	80.16	670.2	11,5	18048.	6836.	.01686
			3	103.29	80.48	661.5	20,1	17781.	11985.	.02954
			4	103.33	80.41	652.9	28,7	17557.	17107.	.04217
			5	102.94	81.11	643.6	38,1	17232.	22705.	.05591
			6	102.82	81.32	634.3	47,3	16962.	28216.	.06945
			7	102.80	81.35	625.0	56,7	16710.	33774.	.08313
			8	102.93	81.12	615.7	66,0	16483.	39337.	.09686
			9	101.76	83.23	604.5	77,1	15981.	46109.	.11316

	S	T_S	i	T_{bi}	ΔT_{ovi}	$W_{\ell i}$	W_{gi}	$Re_{\ell i}$	Re_{gi}	x_{bi}
RUN 61	67.	147.80								
			1	104.28	78.34	718.2	4.2	19515.	2474.	.00577
			2	103.71	79.36	709.2	13.2	19149.	7851.	.01828
			3	102.95	80.73	699.7	22.7	18736.	13509.	.03139
			4	102.81	80.96	690.9	31.5	18472.	18771.	.04360
			5	102.36	81.78	681.4	40.9	18132.	24418.	.05665
			6	102.07	82.31	672.0	50.4	17823.	30100.	.06977
			7	102.53	81.49	663.2	59.2	17677.	35316.	.08197
			8	102.56	81.42	653.5	68.9	17426.	41067.	.09533
			9	101.40	83.52	642.1	80.3	16907.	48043.	.11115
RUN 62	71.	147.80								
			1	104.10	78.66	808.7	3.2	21931.	1908.	.00396
			2	104.04	78.76	800.3	11.7	21688.	6931.	.01437
			3	103.94	78.95	791.5	20.4	21428.	12104.	.02509
			4	104.00	78.83	782.9	29.0	21209.	17226.	.03572
			5	103.38	79.97	773.1	38.9	20798.	23117.	.04785
			6	102.96	80.70	763.4	48.6	20444.	28979.	.05981
			7	102.90	80.81	753.9	58.0	20179.	34545.	.07141
			8	103.15	80.36	744.8	67.2	19988.	39991.	.08273
			9	101.96	82.50	733.3	78.7	19426.	46938.	.09688
RUN 63	75.	147.90								
			1	105.28	76.72	916.2	4.2	25174.	2492.	.00457
			2	104.44	78.23	906.7	13.7	24682.	8126.	.01488
			3	104.45	78.21	898.4	22.0	24458.	13055.	.02391
			4	104.40	78.30	889.7	30.8	24206.	18249.	.03342
			5	103.68	79.60	879.4	41.0	23738.	24387.	.04457
			6	103.56	79.80	869.8	50.6	23450.	30082.	.05496
			7	103.50	79.91	860.0	60.4	23170.	35920.	.06561
			8	103.61	79.71	850.3	70.1	22935.	41700.	.07619
			9	102.30	82.08	837.9	82.6	22278.	49273.	.08970

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	S	Ts	i	Tbi	ΔTovi	Wli	Wgi	ReLi	Regi	Xbi
RUN 64	78.	147.80								
			1	104.31	78.28	948.9	2.8	25794.	1681.	.00298
			2	104.16	78.55	940.9	10.9	25532.	6464.	.01144
			3	104.12	78.62	932.7	19.1	25298.	11345.	.02007
			4	104.12	78.62	924.2	27.6	25070.	16375.	.02897
			5	103.44	79.85	914.2	37.6	24611.	22364.	.03950
			6	103.20	80.28	904.6	47.2	24290.	28075.	.04955
			7	103.15	80.37	895.1	56.7	24020.	33765.	.05958
			8	103.27	80.15	885.5	66.2	23797.	39431.	.06961
			9	101.88	82.66	873.1	78.7	23110.	47004.	.08265

	S	Ts	i	Tbi	ΔTovi	Wli	Wgi	ReLi	Regi	Xbi
RUN 65	79.	149.45								
			1	105.27	79.52	877.0	3.8	24095.	2246.	.00431
			2	104.78	80.41	867.9	12.9	23714.	7656.	.01467
			3	104.67	80.59	859.1	21.7	23446.	12878.	.02466
			4	104.63	80.67	850.1	30.7	23190.	18216.	.03488
			5	104.01	81.78	839.8	41.0	22753.	24339.	.04652
			6	103.81	82.15	829.9	50.9	22434.	30233.	.05776
			7	103.82	82.13	820.1	60.7	22170.	36088.	.06894
			8	103.77	82.22	809.8	71.0	21881.	42185.	.08058
			9	102.37	84.73	797.2	83.6	21213.	49902.	.09495

	S	Ts	i	Tbi	ΔTovi	Wli	Wgi	ReLi	Regi	Xbi
RUN 66	79.	145.75								
			1	105.60	72.27	1008.3	3.8	27805.	2218.	.00371
			2	104.94	73.46	999.2	12.9	27349.	7644.	.01275
			3	104.63	74.02	990.4	21.6	27017.	12833.	.02138
			4	104.56	74.13	981.9	30.1	26766.	17866.	.02977
			5	104.10	74.97	972.5	39.6	26372.	23506.	.03911
			6	103.84	75.43	963.2	48.9	26046.	29057.	.04831
			7	103.74	75.62	953.9	58.2	25764.	34595.	.05751
			8	103.83	75.45	944.7	67.4	25543.	40045.	.06658
			9	102.30	78.26	932.3	79.8	24789.	47622.	.07884

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 67	84.	148.93								
			1	105.73	77.76	982.3	4.4	27127.	2616.	.00449
			2	104.98	79.11	972.3	14.4	26627.	8538.	.01461
			3	105.00	79.07	963.6	23.2	26393.	13725.	.02348
			4	104.96	79.15	954.5	32.2	26131.	19096.	.03267
			5	104.22	80.48	944.0	42.8	25632.	25393.	.04335
			6	103.97	80.92	934.1	52.6	25296.	31268.	.05335
			7	103.88	81.09	924.3	62.5	25004.	37118.	.06331
			8	104.02	80.84	914.6	72.2	24780.	42856.	.07312
			9	102.62	83.35	901.9	84.8	24065.	50586.	.08598
RUN 68	89.	148.25								
			1	104.64	78.50	1032.2	5.1	28159.	3052.	.00496
			2	104.13	79.41	1022.9	14.5	27749.	8587.	.01394
			3	104.96	77.93	1015.8	21.5	27809.	12757.	.02076
			4	104.54	78.67	1006.1	31.2	27419.	18517.	.03010
			5	103.71	80.18	995.3	42.0	26874.	24961.	.04048
			6	103.77	80.06	986.1	51.3	26643.	30473.	.04942
			7	103.63	80.31	976.1	61.2	26336.	36376.	.05898
			8	103.74	80.13	966.5	70.9	26103.	42127.	.06832
			9	102.35	82.61	953.8	83.5	25376.	49836.	.08051
RUN 69	104.	147.93								
			1	106.11	75.28	1197.1	4.1	33202.	2429.	.00342
			2	105.28	76.76	1187.1	14.1	32621.	8348.	.01174
			3	105.36	76.63	1176.9	22.4	32421.	13233.	.01862
			4	105.49	76.30	1170.5	30.8	32236.	18207.	.02562
			5	104.57	78.06	1159.4	41.8	31604.	24811.	.03483
			6	104.12	78.86	1149.1	52.1	31169.	30943.	.04338
			7	103.96	79.15	1139.2	62.1	30845.	36864.	.05166
			8	103.92	79.23	1129.2	72.0	30559.	42802.	.05997
			9	102.33	82.09	1115.5	85.7	29669.	51145.	.07134

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 70	35.	150.65								
			1	103.14	85.52	333.6	4.2	8952.	2510.	.01248
			2	101.73	88.05	324.3	13.5	8571.	8079.	.04001
			3	101.50	86.47	315.5	22.4	8316.	13379.	.06621
			4	102.23	87.15	306.9	30.9	8154.	18470.	.09159
			5	101.86	87.82	297.3	40.5	7868.	24199.	.11987
			6	101.62	88.25	287.6	50.3	7590.	30050.	.14875
			7	101.58	88.32	277.6	60.2	7326.	35990.	.17814
			8	101.98	87.61	267.7	70.1	7093.	41899.	.20762
			9	101.29	88.86	256.9	80.9	6757.	48435.	.23954
RUN 71	42.	151.10								
			1	103.42	85.81	386.8	4.5	10411.	2707.	.01163
			2	102.61	87.28	377.4	14.0	10067.	8339.	.03574
			3	102.72	87.08	366.4	23.0	9840.	13694.	.05870
			4	102.83	86.89	359.2	32.2	9605.	19174.	.08222
			5	102.31	87.82	349.3	42.1	9288.	25100.	.10747
			6	102.29	87.85	339.5	51.8	9027.	30927.	.13241
			7	102.17	88.08	329.4	61.9	8747.	36954.	.15816
			8	102.39	87.68	319.4	72.0	8500.	42947.	.18392
			9	101.65	89.01	308.4	82.9	8144.	49566.	.21183
RUN 72	56.	151.15								
			1	103.39	85.96	556.5	4.1	14976.	2428.	.00728
			2	102.99	86.68	547.4	13.2	14665.	7890.	.02363
			3	102.93	86.80	538.4	22.3	14413.	13258.	.03969
			4	102.89	86.87	529.2	31.4	14161.	18730.	.05607
			5	102.22	88.07	519.1	41.5	13791.	24771.	.07402
			6	101.99	88.49	509.2	51.4	13495.	30689.	.09164
			7	101.97	88.52	499.3	61.3	13229.	36630.	.10938
			8	102.30	87.93	489.4	71.2	13013.	42491.	.12699
			9.	101.39	89.57	478.1	82.5	12588.	49389.	.14723

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 73	71.	151.40								
			1	104.68	83.73	741.4	4.6	20282.	2699.	.00611
			2	104.23	84.90	731.3	14.6	19863.	8687.	.01962
			3	103.55	86.13	721.1	24.9	19436.	14813.	.03339
			4	103.59	86.05	711.6	34.4	19190.	20442.	.04608
			5	102.91	87.28	700.9	45.1	18761.	26855.	.06042
			6	102.58	87.87	690.4	55.6	18415.	33130.	.07447
			7	103.24	86.69	681.0	65.0	18293.	38687.	.08712
			8	103.47	86.27	670.7	75.3	18064.	44780.	.10091
			9	102.22	88.52	658.2	87.8	17485.	52412.	.11769
RUN 74	76.	151.40								
			1	104.76	83.94	797.3	4.0	21781.	2399.	.00505
			2	104.31	84.75	787.8	13.6	21414.	8045.	.01692
			3	103.66	85.94	777.7	23.7	20986.	14062.	.02952
			4	103.71	85.84	768.4	33.0	20747.	19594.	.04113
			5	103.71	85.83	756.7	42.6	20488.	25337.	.05319
			6	103.36	86.47	748.3	53.1	20127.	31584.	.06624
			7	103.13	86.89	737.7	63.6	19793.	37886.	.07940
			8	103.13	86.89	727.2	74.1	19511.	44143.	.09251
			9	101.90	89.09	714.7	86.6	18922.	51764.	.10811
RUN 75	35.	151.35								
			1	103.51	86.11	376.1	4.1	10133.	2451.	.01084
			2	102.89	87.22	367.2	13.0	9827.	7752.	.03422
			3	102.80	87.39	358.4	21.8	9581.	13003.	.05738
			4	102.63	87.70	349.3	30.9	9320.	18444.	.08136
			5	102.10	88.64	339.6	40.6	9012.	24224.	.10669
			6	102.19	88.49	330.2	50.1	8768.	29888.	.13167
			7	102.26	88.36	320.4	59.9	8514.	35726.	.15742
			8	102.54	87.86	310.4	69.8	8275.	41623.	.18355
			9	101.75	89.27	299.6	80.7	7918.	48211.	.21213

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 76	32.	151.35								
			1	103.42	86.26	327.5	4.4	8815.	2610.	.01322
			2	102.78	87.43	318.4	13.5	8510.	8040.	.04065
			3	102.45	88.03	309.3	22.6	8237.	13463.	.06800
			4	102.13	88.60	300.0	31.8	7963.	19012.	.09594
			5	101.72	89.33	290.5	41.4	7676.	24742.	.12471
			6	101.67	89.42	280.9	51.0	7419.	30464.	.15353
			7	101.73	89.32	271.2	60.7	7166.	36280.	.18287
			8	102.23	88.41	261.4	70.4	6947.	42047.	.21224
			9	101.58	89.59	250.8	81.1	6617.	48485.	.24428
RUN 77	24.	151.35								
			1	102.49	87.96	229.2	4.3	6107.	2567.	.01843
			2	101.89	89.02	220.3	13.2	5832.	7903.	.05664
			3	101.85	89.09	211.5	22.0	5597.	13150.	.09424
			4	101.85	89.10	202.6	30.9	5361.	18458.	.13228
			5	101.45	89.82	193.4	40.1	5095.	23995.	.17176
			6	101.42	89.88	184.1	49.4	4849.	29548.	.21149
			7	101.35	89.99	174.6	58.9	4595.	35267.	.25238
			8	101.80	89.19	164.9	68.6	4361.	40999.	.29377
			9	101.24	90.20	154.5	79.0	4062.	47281.	.33824
RUN 78	29.	151.30								
			1	102.39	88.04	278.6	4.2	7415.	2501.	.01482
			2	101.58	89.49	269.7	13.1	7116.	7825.	.04627
			3	101.21	90.15	260.8	22.0	6853.	13170.	.07780
			4	101.21	90.17	251.8	31.0	6617.	18535.	.10949
			5	100.92	90.68	242.4	40.3	6351.	24164.	.14263
			6	100.71	91.07	232.8	49.9	6085.	29945.	.17664
			7	100.58	91.29	223.0	59.8	5820.	35869.	.21151
			8	101.22	90.14	213.2	69.6	5603.	41659.	.24609
			9	100.69	91.09	202.7	80.1	5296.	48035.	.28333

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 79	36.	151.30								
			1	103.21	86.57	375.2	4.4	10074.	2620.	.01159
			2	102.34	88.13	365.8	13.7	9731.	8192.	.03617
			3	101.99	88.75	356.7	22.9	9452.	13680.	.06034
			4	101.96	88.81	347.5	32.1	9205.	19158.	.08449
			5	101.65	89.37	337.9	41.7	8921.	24912.	.10977
			6	101.52	89.60	328.2	51.4	8653.	30730.	.13536
			7	101.52	89.60	318.3	61.3	8393.	36636.	.16138
			8	101.94	88.84	308.4	71.1	8169.	42490.	.18738
			9	101.18	90.22	297.5	82.0	7816.	49105.	.21609
RUN 80	27.	151.20								
			1	103.29	86.25	272.6	4.4	7328.	2610.	.01583
			2	102.60	87.47	263.5	13.5	7030.	8048.	.04871
			3	102.34	87.94	254.5	22.5	6771.	13437.	.08128
			4	102.25	88.12	245.4	31.6	6521.	18892.	.11424
			5	102.00	88.57	235.9	41.1	6253.	24545.	.14832
			6	101.97	88.61	226.4	50.6	5998.	30251.	.18279
			7	101.93	88.68	216.6	60.4	5737.	36100.	.21812
			8	102.34	87.94	206.8	70.2	5501.	41916.	.25355
			9	101.75	89.01	196.3	80.7	5189.	48253.	.29139
RUN 81	33.	151.25								
			1	103.47	86.00	359.8	4.4	9690.	2605.	.01202
			2	102.62	87.54	350.5	13.7	9352.	8158.	.03757
			3	102.30	88.10	341.3	22.9	9076.	13642.	.06276
			4	102.08	88.50	332.0	32.2	8807.	19231.	.08842
			5	101.76	89.07	322.3	41.8	8522.	25013.	.11490
			6	101.93	88.77	312.8	51.4	8284.	30714.	.14116
			7	102.02	88.61	302.9	61.3	8031.	36585.	.16818
			8	102.30	88.11	293.0	71.2	7791.	42481.	.19544
			9	101.50	89.55	282.2	82.0	7439.	49043.	.22512

	S	Ts	i	Tbi	ΔTovi	WLi	Wgi	ReLi	Regi	Xbi
RUN 82	32.	147.80								
			1	101.00	83.15	327.4	3.4	8641.	2046.	.01034
			2	101.80	82.79	319.7	11.2	8455.	6667.	.03371
			3	101.77	82.85	311.7	19.2	8241.	11452.	.05791
			4	101.83	82.75	303.6	27.3	8031.	16291.	.08239
			5	101.58	83.20	295.1	35.7	7787.	21361.	.10796
			6	101.55	83.25	286.6	44.2	7559.	26465.	.13374
			7	101.60	83.15	277.9	53.0	7334.	31673.	.16008
			8	101.53	82.56	269.1	61.8	7127.	36900.	.18668
			9	101.08	84.10	259.4	71.4	6808.	42783.	.21592
RUN 83	31.	148.75								
			1	99.99	87.77	297.3	3.2	7711.	1899.	.01052
			2	101.19	85.61	290.3	10.1	7626.	6074.	.03377
			3	101.73	84.63	282.7	17.7	7472.	10561.	.05881
			4	101.72	84.65	274.8	25.7	7260.	15337.	.08540
			5	101.45	85.15	266.4	34.0	7019.	20324.	.11309
			6	101.37	85.28	258.0	42.4	6792.	25368.	.14112
			7	101.43	85.17	249.4	51.0	6570.	30515.	.16978
			8	101.95	84.24	240.7	59.7	6377.	35647.	.19862
			9	101.15	85.68	231.2	69.2	6071.	41461.	.23050
RUN 84	28.	151.10								
			1	103.40	85.86	268.9	4.2	7236.	2524.	.01553
			2	102.70	87.11	260.1	13.1	6946.	7783.	.04780
			3	102.47	87.53	251.4	21.8	6696.	12977.	.07965
			4	102.54	87.42	242.7	30.5	6469.	18165.	.11151
			5	102.29	87.85	233.6	39.5	6211.	23587.	.14469
			6	102.20	88.02	224.4	48.8	5959.	29119.	.17858
			7	102.27	87.89	214.9	58.3	5711.	34778.	.21333
			8	102.68	87.16	205.2	67.9	5479.	40497.	.24869
			9	102.00	88.38	194.8	78.4	5162.	46815.	.28694

	S	T_s	i	T_{bi}	ΔT_{ovi}	W_{Li}	W_{gi}	Re_{Li}	Re_{gi}	X_{bi}
RUN 85	24.	151.10								
			1	103.00	86.57	249.9	4.2	6695.	2505.	.01655
			2	102.42	87.63	241.1	13.0	6419.	7737.	.05104
			3	102.14	88.13	232.3	21.8	6166.	13003.	.08571
			4	102.01	88.35	223.4	30.7	5921.	18341.	.12085
			5	101.74	88.85	214.2	39.9	5660.	23862.	.15711
			6	101.77	88.78	204.9	49.2	5416.	29415.	.19369
			7	101.90	88.56	195.4	58.7	5172.	35077.	.23106
			8	102.27	87.89	185.7	68.4	4936.	40812.	.26911
			9	101.61	89.08	175.3	78.8	4627.	47092.	.30994

Table 4.7

Local Results - II

i:	Compartment number, counted from the bottom of the tube	-
x_{bi}:	Two phase mixture quality	-
q_i:	Heat flux	BTU/hr ft²
h_{TPi}:	Two-phase heat transfer coefficient	BTU/hr ft² ^{o}F
h_{Li}:	Liquid phase heat transfer coefficient	BTU/hr ft² ^{o}F
$(1/X_{tt})i$:	Lockhart-Martinelli parameter	-
ΔT_{fi}:	Film temperature difference	^{o}F
$T_{bi}/\Delta T_{fi}$:	Dimensionless reciprocal of the film temperature difference	-
Fr_i:	Homogeneous Froude number	-
Fr_{Li}:	Liquid phase Froude number	-
Fr_{gi}:	Vapour phase Froude number	-

	i	x_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 1												
	1	,00062	15753.	1003.0	510.3	1.965	0,036	15.71	43.13	1.7	0.481	0.4
	2	,00400	16538.	1050.7	508.1	2.068	0,195	15.74	42,99	22,5	0.477	16.4
	3	,00739	17212.	1093.3	506.0	2.160	0,342	15.74	42.96	68,0	0.474	57.1
	4	,01058	17960.	1166.9	504.5	2.313	0,475	15.39	43.92	133,4	0.471	118.0
	5	,01447	18709.	1200.3	501.9	2.392	0,636	15.59	43.32	248,3	0.467	227.3
	6	,01789	19420.	1273.9	500.2	2.547	0,773	15.24	44,29	376,0	0.463	350,1
	7	,02122	20093.	1364.8	498.9	2.736	0,904	14.72	45,86	522,8	0.460	492,2
	8	,02472	20804.	1461.6	497.4	2.939	1,041	14.23	47,42	705,2	0.457	669,8
	9	,02972	21440.	1415.2	493.6	2.867	1,251	15,15	44.47	1066.0	0.452	1022.6
RUN 2												
	1	,00066	15223.	1262.5	746.5	1.691	0,037	12.06	56,40	4,4	1.226	1.0
	2	,00334	15365.	1185.0	742.9	1.595	0,163	12.97	52,37	39,5	1.218	26,9
	3	,00544	15577.	1176.0	740.8	1.588	0,254	13.25	51,23	92,4	1.212	72,4
	4	,00748	16002.	1205.4	738.9	1.631	0,340	13.28	51,09	165,6	1.207	138,6
	5	,01029	16569.	1192.9	735.2	1.623	0,458	13,89	48,75	309,9	1.199	272,5
	6	,01251	17241.	1250.0	733.1	1.705	0,549	13,79	49,06	454,3	1.193	409,0
	7	,01458	18126.	1361.8	731.5	1.862	0,633	13,31	50,83	612,1	1.188	559,4
	8	.01686	19295.	1518.0	729.6	2.081	0,725	12,71	53,21	817,0	1.182	756,0
	9	,02057	20746.	1577.7	724.5	2.178	0,882	13,15	51,31	1270,1	1.172	1194,1
RUN 3												
	1	.00027	16173.	1104.3	766.2	1.441	0,017	14.64	46,34	2,5	1.318	0.2
	2	,00179	16572.	1167.8	765.6	1.525	0,093	14,19	47,84	16,2	1.315	8.3
	3	,00325	17115.	1265.3	765.2	1.654	0,159	13.53	50,20	40,5	1.311	27.2
	4	.00552	17913.	1337.9	762.9	1.754	0,257	13.39	50,68	101,8	1.305	80.1
	5	,00865	18602.	1322.1	758.6	1.743	0,390	14,07	48,15	238,8	1.295	204.9
	6	,01114	19509.	1402.4	756.0	1.855	0,494	13,91	48,66	390,7	1.288	347.2
	7	,01326	20343.	1523.0	754.6	2.018	0,579	13,36	50,67	544,9	1.282	493,3
	8	,01566	21794.	1669.4	752.6	2.218	0,676	12,82	52,79	755,6	1.276	694,7
	9	,01950	22663.	1692,6	747.2	2.265	0,838	13,39	50,41	1220,0	1.264	1142,8

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 4											
1	,00066	16553.	1301.1	823.6	1.580	0,037	12.72	53.50	5,6	1.562	1.2
2	,00322	17313.	1324.4	820.0	1.615	0,156	13.07	52,00	46,2	1.552	30.9
3	,00532	18002.	1387.6	817.7	1.697	0,247	12.97	52,37	110,2	1.545	85.7
4	,00764	18726.	1440.7	814.9	1.768	0,345	13.00	52,22	215,4	1.537	180.5
5	,01040	19378.	1443.1	811.1	1.779	0,460	13.43	50,48	393,0	1.528	345.5
6	,01263	20102.	1517.7	808.9	1.876	0,551	13.25	51,15	574,6	1.520	517.0
7	,01500	20827.	1586.9	806.4	1.968	0,647	13.12	51,59	809,4	1.512	740.9
8	,01747	21515.	1646.7	803.8	2.049	0,747	13.07	51,78	1102,5	1.504	1022.6
9	,02137	22167.	1544.2	797.6	1.936	0,913	14.36	47,01	1736,9	1.490	1636.7
RUN 5											
1	,00125	19162.	1689.2	919.0	1.838	0,066	11.34	60,11	14,5	2.039	5.7
2	,00472	19827.	1570.3	912.2	1.721	0,221	12.63	53,86	114,3	2.022	85.9
3	,00697	20531.	1623.3	909.2	1.785	0,315	12.65	53,73	231,8	2.012	190.6
4	,00908	21313.	1714.8	906.7	1.891	0,402	12.43	54,65	381,3	2.003	328.1
5	,01203	22134.	1713.8	901.9	1.900	0,524	12.92	52,50	670,1	1.989	599.0
6	,01441	23072.	1816.7	899.0	2.021	0,621	12.70	53,35	960,7	1.979	875.5
7	,01667	24050.	1960.9	896.6	2.187	0,711	12.27	55,22	1284,3	1.969	1185.7
8	,01916	25223.	2133.6	893.7	2,387	0,811	11.82	57,25	1708,2	1.958	1594.5
9	,02331	26318.	2033.0	886.2	2,294	0,988	12.95	52,13	2683,5	1.939	2541.2
RUN 6											
1	.00033	15804.	1121.8	966.0	1.161	0,020	14.09	48,26	4.9	2.337	0.5
2	,00200	16523.	1183.7	963.7	1.228	0,102	13.96	48,68	33,3	2.328	18.0
3	.00323	17349.	1308.2	962.9	1.359	0,157	13.26	51,24	70,0	2.323	46.9
4	,00504	18139.	1385.3	960.4	1.442	0,236	13.09	51,87	151,1	2.314	116.0
5	,00773	18857.	1370.4	955.3	1.434	0,351	13.76	49,26	338,3	2.299	284.9
6	,00987	19648.	1424.0	952.1	1.496	0,441	13.80	49,08	543,9	2.288	475.6
7	,01184	20474.	1507.4	949.6	1.588	0,522	13.58	49,83	776,9	2.278	695.0
8	,01400	21192.	1560.3	946.5	1.648	0,611	13.58	49,79	1089,9	2.267	992.8
9	.01768	21910.	1461.5	939.0	1.557	0,770	14.99	44,98	1831,9	2.246	1705.8

RUN	i	X_{ti}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Frg_i
RUN 7	1	,00074	15896.	1348.4	952.6	1.416	0,041	11,79	57,81	8,9	2.236	2.2
	2	,00352	16072.	1319.1	946.9	1.393	0,169	12,64	53,80	76,2	2.221	52.4
	3	,00561	17560.	1385.1	943.5	1.468	0,259	12,68	53,59	173,3	2.210	136.4
	4	,00751	18447.	1479.1	940.9	1.572	0,339	12,47	54,43	297,5	2.201	248.5
	5	,01008	19223.	1486.4	936.6	1.587	0,447	12,93	52,41	531,4	2.187	465.4
	6	,01226	20110.	1562.8	933.2	1.675	0,537	12,87	52,63	784,3	2.177	703,8
	7	,01444	20998.	1648.2	930.5	1.772	0,627	12,74	53.11	1091,7	2.166	996.7
	8	,01660	21811.	1734.2	927.5	1.870	0,715	12,58	53.76	1448,3	2.156	1338.7
	9	,02033	22024.	1629.3	920.1	1.771	0,876	13,89	48.56	2301,5	2.136	2163.4
RUN 8	1	,00202	22383.	1145.7	490.8	2.334	0,104	19.54	34.73	6,5	0.433	3.5
	2	,00741	23055.	1134.8	487.1	2.330	0,340	20.32	33,34	59,6	0.428	50.0
	3	,01200	23806.	1181.8	484.8	2.438	0,528	20,14	33,60	148,5	0.424	133,1
	4	,01615	24597.	1268.2	483.3	2.624	0,692	19.39	34.91	260,3	0.421	239.8
	5	,02147	25427.	1297.3	480.2	2.702	0,906	19.60	34.50	464,8	0.416	437.4
	6	,02643	26297.	1360.7	477.7	2.848	1,102	19.33	34.96	708,8	0.411	675.0
	7	,03085	27128.	1480.9	476.4	3.108	1,266	18.32	36,91	942,4	0.408	903.6
	8	,03549	27800.	1582.5	474.9	3.332	1,439	17.57	38,50	1229,7	0.404	1185.5
	9	,04226	28275.	1491.3	470.1	3.172	1,722	18,96	35,58	1852,2	0.398	1798.3
RUN 9	1	,00142	22008.	1000.1	491.8	2.033	0,077	22,01	30,75	4,2	0.440	1.9
	2	,00620	23215.	1062.2	488.9	2.172	0,293	21,86	30,92	46,0	0.436	37,5
	3	,01097	24140.	1111.8	486.6	2.286	0,494	21,71	31,10	134,6	0.431	119.8
	4	,01523	24945.	1186.0	484.8	2.447	0,666	21,03	32,11	250,7	0.428	230.4
	5	,02031	25830.	1233.2	482.0	2.558	0,871	20,94	32,22	446,5	0.423	419.5
	6	,02521	26595.	1289.4	479.8	2.688	1,066	20,63	32,70	686,2	0.419	652.7
	7	,02968	27439.	1393.1	478.3	2.912	1,236	19,70	34,26	934,3	0.415	895.3
	8	,03443	28244.	1492.7	476.7	3.131	1,417	18,92	35,67	1242,3	0.411	1197.5
	9	,04119	28928.	1440.0	471.9	3.051	1,703	20,09	33,51	1887,1	0.405	1832.2

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 10												
	1	,00158	23553.	1193.0	595.7	2.003	0,083	19.74	34.38	7,3	0.702	3.5
	2	,00640	23559.	1148.1	591.1	1.942	0,298	20.87	32,45	74,0	0.695	60,3
	3	,01045	24527.	1164.1	588.2	1.979	0,467	21.07	32,11	186,9	0.689	164.9
	4	,01401	25177.	1219,1	586.4	2.079	0,610	20.65	32,76	326,1	0.684	296.9
	5	,01861	26070.	1244,2	582.7	2.135	0,798	20.95	32,24	583,1	0.677	544.0
	6	,02269	27045.	1315,3	580.3	2.267	0,961	20,56	32,84	867,3	0.671	819.7
	7	,02634	28101.	1437,4	578.8	2.483	1,100	19,55	34,55	1150,8	0.666	1096,1
	8	,03031	29360.	1583,5	577.0	2.745	1,253	18,54	36,43	1512,3	0.661	1449,8
	9	,03636	30781.	1598.9	571.4	2.798	1,509	19.25	34,99	2315,9	0.651	2238.8
RUN 11												
	1	,00033	21904.	996.1	641.6	1.553	0,021	21.99	30,81	1,9	0.851	0.2
	2	,00298	23121.	1108.7	640.6	1.731	0,148	20.85	32,50	23,5	0.847	15,5
	3	,00617	24216.	1199.7	638.7	1.878	0,287	20.19	33,57	82,6	0.841	66.8
	4	,00948	25352.	1301.7	636.7	2.045	0,424	19.48	34,79	182,7	0.835	156.8
	5	,01349	26528.	1377.8	633.5	2.175	0,588	19,25	35,15	363,5	0.828	329.7
	6	,01723	27705.	1486.8	631.1	2.356	0,737	18,63	36,31	586,8	0.822	543.7
	7	,02095	28800.	1609.3	629.0	2.558	0,882	17.90	37,80	857,8	0.815	805.7
	8	,02476	30017.	1761.2	626.9	2.809	1,031	17.04	39,68	1192,4	0.809	1131.0
	9	,03039	31234.	1755,2	621.3	2.825	1,265	17,80	37,91	1894,9	0.799	1817,9
RUN 12												
	1	,00086	22191.	1116.8	706.4	1.581	0.048	19.87	34.12	5,4	1.081	1.6
	2	,00386	23020.	1170.5	703.9	1.663	0.188	19.67	34,45	46,5	1.074	33.4
	3	,00661	23968.	1258.8	702.1	1.793	0.306	19.04	35,58	120,1	1.068	98.5
	4	,00982	24876.	1324.3	699.5	1.893	0,440	18.78	36,04	252,6	1.060	221.0
	5	,01381	25784.	1344.2	695.3	1.933	0,606	19.18	35,23	500,4	1.051	455.6
	6	,01700	26455.	1399,2	693.1	2.019	0,735	18,91	35,73	752,0	1.044	697.0
	7	,02009	27956.	1573.4	691.3	2.276	0,856	17.77	38,02	1037,9	1.037	973.3
	8	,02362	28582.	1675.5	688.7	2.433	0,997	17.30	39,04	1439,1	1.030	1363.2
	9	,02893	30048.	1632,2	682.3	2,392	1,224	18,41	36,57	2302,0	1.017	2206.3

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 13												
	1	,00062	21486.	1097.0	785.8	1.396	0,035	19.59	34,71	4,8	1.395	1.0
	2	,00339	22736.	1185,4	782.9	1.514	0,165	19.18	35,42	45,6	1.386	31.1
	3	,00590	23784.	1281,0	781.0	1.640	0,272	18.57	36,58	119,1	1.379	94.8
	4	,00884	24993.	1378,3	778.1	1.771	0,394	18.13	37.43	252,3	1.370	216.5
	5	,01270	26162.	1414.1	773.1	1.829	0,554	18.50	36,61	519,7	1.358	468.0
	6	,01569	27291.	1520.0	770.6	1.972	0,674	17.95	37,71	786,6	1.350	722,8
	7	,01841	28420.	1668,0	769.0	2.169	0,780	17.04	39,74	1068,1	1.342	993,7
	8	,02184	29548.	1769,9	765.8	2.311	0,916	16.69	40.53	1514,0	1.332	1425.5
	9	,02707	30677.	1704.2	758.2	2.248	1,139	18.00	37,47	2494,3	1.315	2381.1
RUN 14												
	1	,00059	21697.	1202,2	908.1	1.324	0,034	18.05	37,70	6,5	1.996	1,3
	2	,00302	22641.	1266.0	905.0	1.399	0,148	17.88	38,02	53,1	1.985	34,6
	3	,00506	23789.	1390.8	903.3	1.540	0,235	17.10	39,75	126,9	1.977	97.2
	4	,00754	24937.	1496,5	900.5	1.662	0,339	16.66	40,77	263,2	1.966	219.7
	5	,01092	26168.	1546,4	895.2	1.727	0,479	16,92	40.08	544,3	1.951	481.0
	6	,01362	27480.	1678.9	892.2	1.882	0,589	16.37	41,40	840,3	1.940	761.5
	7	,01623	28711.	1831,3	889.7	2.058	0,692	15.68	43,21	1184,6	1.929	1091.0
	8	,01896	29982.	2001,3	887.0	2.256	0,801	14.98	45,20	1614,9	1.918	1505,5
	9	,02366	31418.	1968.8	878.9	2.240	1,000	15.96	42,30	2678,5	1.896	2537.9
RUN 15												
	1	,00055	23053.	1130.0	899.3	1.256	0,032	20.40	33,33	6,0	1.953	1.1
	2	,00277	24260.	1232.0	897.2	1.373	0,137	19.70	34,51	45,5	1.944	28.7
	3	,00474	25479.	1366.2	896.0	1.525	0,222	18.65	36,45	111,0	1.937	83.6
	4	,00743	26693.	1467.2	893.0	1.643	0,334	18.19	37,34	250,7	1.926	208.7
	5	,01103	27906.	1507.3	887.4	1.698	0,484	18,51	36,63	544,3	1.909	481.7
	6	,01402	29119.	1604.2	884.0	1.815	0,605	18.15	37,33	874,3	1.897	794.8
	7	,01682	30333.	1733.4	881.3	1.967	0,717	17,50	38,70	1250,5	1.886	1155.3
	8	,01981	31627.	1874.6	878.3	2.134	0,835	16.87	40,12	1737,3	1.874	1625.1
	9	,02474	32880.	1820.9	869.9	2.093	1,045	18.06	37,36	2897,3	1.851	2752.7

i	X_{ti}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 16											
1	,00189	28134.	1207.9	579.0	2.086	0,097	23.29	29,17	8,6	0.651	4,5
2	,00726	29306.	1245.7	574.8	2.167	0,330	23.53	28,83	83,1	0.644	69,1
3	,01215	30436.	1313.0	571.7	2.297	0,530	23.18	29,24	220,6	0.637	197,6
4	,01671	31692.	1423.8	569.5	2.500	0,709	22.26	30,45	406,0	0.631	374,7
5	,02212	32739.	1477.8	566.6	2.611	0,923	22.15	30.56	715,6	0.624	674,0
6	,02734	33911.	1569.4	563.0	2.787	1,126	21.61	31,32	1094,7	0.617	1043.3
7	,03224	35083.	1704.4	560.9	3.039	1,311	20.58	32,88	1504,8	0.611	1444,7
8	,03733	36214.	1845.9	558.7	3.304	1,502	19.62	34,50	2000,0	0.605	1931.1
9	,04466	37302.	1798.8	552.4	3,256	1,809	20.74	32,54	3065,3	0.594	2980,5
RUN 17											
1	,00186	30619.	1230.1	604.8	2.034	0,096	24,89	27.31	9,3	0.726	4,9
2	,00717	31452.	1246.5	600.7	2.075	0,326	25.23	26,90	89,5	0.717	74,2
3	,01198	32285.	1292.9	597.8	2.163	0,520	24.97	27.16	234,7	0.710	209,6
4	,01666	33465.	1365,2	595.2	2.294	0,705	24.38	27,81	444,4	0.703	409,7
5	,02213	34243.	1402.1	591.3	2.371	0,921	24.42	27.73	789,9	0.695	743,7
6	,02680	35368.	1509,1	589.2	2.561	1,099	23.44	28,90	1142,4	0.689	1087.0
7	,03161	36576.	1636.7	587.1	2.788	1,278	22.35	30,37	1568,0	0.682	1503.3
8	,03699	37909.	1758,3	584.1	3.010	1,484	21.56	31,41	2155,0	0.674	2079,4
9	,04444	39242.	1735.0	577.3	3.005	1,796	22,62	29,85	3343.0	0.663	3249,6
RUN 18											
1	,00109	28555.	1261.3	687.5	1.747	0,059	23.77	28.60	6,2	0.999	2.2
2	,00503	30337.	1327.1	684.5	1.939	0,235	22.86	29.72	64,0	0.991	49.0
3	,00887	31[illegible]49.	1467,0	682.1	2.151	0,393	21.78	31.19	178,8	0.983	153.3
4	,01283	33435.	1608.6	679.6	2.367	0,553	20.79	32.67	361,4	0.975	324.9
5	,01791	34792.	1679.8	675.1	2.488	0,754	20.71	32.74	702,3	0.964	651.2
6	,02231	36108.	1813.0	672.2	2.697	0.924	19.92	34.03	1082.7	0.955	1019.3
7	,02658	37338.	1975.0	670.0	2,948	1,086	18,91	35,86	1518,8	0.947	1443,9
8	.03155	38399.	2066.4	666.4	3.101	1,278	18.58	36.45	2161,8	0.937	2072.8
9	.03838	39460.	1976.8	658.8	3.001	1,565	19.96	33.82	3446,9	0.922	3335.1

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 19												
	1	,00097	27977.	1150.5	687.1	1.674	0,053	24.32	27.96	5,4	0.997	1.8
	2	,00435	29346,	1261.2	685.5	1.841	0,205	23.27	29,22	48,8	0.990	35.9
	3	,00803	30675.	1370.4	683.0	2.007	0,358	22.38	30.37	145,9	0.983	122.9
	4	,01227	31961.	1458.4	679.7	2.146	0,528	21.91	31.00	326,7	0.974	292.0
	5	,01718	33248.	1515.7	675.2	2.245	0,724	21.94	30.92	641,9	0.963	593.2
	6	,02156	34018.	1628.1	672.1	2.423	0,896	21.26	31,88	1010,7	0.955	949.5
	7	,02565	35988.	1787.2	669.9	2.668	1,051	20.14	33,66	1414,0	0.947	1341.8
	8	,03025	37274.	1919.9	666.9	2.879	1,227	19.41	34.90	1970,6	0.937	1885.6
	9	,03712	38520.	1851.7	659.0	2.810	1,516	20.80	32,46	3212,1	0.922	3104.2
RUN 20												
	1	,00190	28882.	1469.2	811.0	1.812	0,094	19,66	34,77	17,7	1.477	8.9
	2	,00672	29842.	1434.0	803.8	1.784	0,300	20,81	32,76	147,4	1.461	119.5
	3	,01024	30677.	1480.6	800.3	1.850	0,441	20,72	32,87	324,2	1.450	282.3
	4	,01340	31720.	1582.4	798.0	1.983	0,564	20,05	33,97	539,9	1.440	485,6
	5	,01758	32555.	1593,6	793.1	2.009	0,730	20.43	33,28	938,6	1.427	866,9
	6	,02141	33598.	1661.2	789.3	2.104	0,879	20.23	33.59	1401,5	1.415	1313.9
	7	,02484	35059.	1826.7	786.9	2.321	1,009	19.19	35,39	1877,0	1.405	1775.6
	8	,02863	36812.	2031.1	783.8	2.591	1,153	18.12	37,46	2500,9	1.394	2384.2
	9	,03479	38649.	2019.5	774.9	2.606	1,412	19.14	35,35	4001,4	1.373	3854,6
RUN 21												
	1	,00177	30543.	1669.6	853.1	1.957	0,088	18.29	37,38	18,0	1.674	8.7
	2	,00640	31584.	1644.2	846.0	1.943	0,286	19.21	35,51	150,7	1.656	120,8
	3	,00985	32582.	1720.6	842.5	2.042	0,424	18,94	35,99	336,3	1.644	290,9
	4	,01301	33797.	1863.7	840.0	2.219	0,548	18.13	37,58	570,0	1.633	510.6
	5	,01739	34838.	1879.8	834.4	2.253	0,721	18.53	36,70	1031,5	1.617	951.4
	6	,02111	36096.	2007.7	830.8	2.411	0,864	18.02	37,71	1522,3	1.604	1425.0
	7	,02463	37398.	2177.7	828.0	2.630	0,998	17.17	39,57	2064,1	1.593	1951.0
	8	,02873	38910.	2344.8	823.9	2.846	1,156	16.60	40.91	2847,2	1.578	2714.7
	9	.03490	40435.	2246.6	814.1	2.760	1,421	18.00	37.58	4600,1	1.555	4432.5

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 22											
1	,00510	33629.	1142,9	315.9	3.618	0,242	29,42	23,02	10,3	0.145	8,0
2	,01669	34101.	1128.0	312.0	3.615	0,719	30.23	22,36	96,7	0.142	89,5
3	,02749	34744.	1158.9	309.1	3.750	1,141	29.98	22,54	256,9	0.138	245,1
4	,03809	35602.	1221,0	306.5	3.984	1,543	29.16	23.18	483,9	0.135	467,9
5	,04971	36331.	1244,7	303.0	4.107	1,993	29,19	23,14	836,2	0.132	815,4
6	,06096	37060.	1293,9	300.1	4.311	2,422	28,64	23,58	1252,8	0.129	1227,5
7	,07213	38690.	1436,2	297.6	4.826	2,837	26,94	25,08	1720,3	0.126	1691,0
8	,08393	39977.	1556.0	294.8	5.279	3,283	25,69	26,31	2302,8	0.123	2269,3
9	,09817	41607,	1588.3	289.7	5.482	3,897	26,20	25,74	3367,3	0.119	3327,3
RUN 23											
1	,00276	32350.	1134.8	472.5	2.402	0,137	28,51	23,82	9,3	0.393	5,9
2	,01005	33253.	1149.9	468.2	2.456	0,446	28,92	23.44	92,9	0.386	81,3
3	,01671	34329.	1208.3	465.3	2.597	0,711	28,41	23,85	246,7	0.381	227,7
4	,02320	35275.	1275.1	462.8	2.755	0,960	27,66	24,49	464,8	0.376	438,7
5	,03090	36480.	1317.4	458.7	2.872	1,262	27,69	24,44	841,7	0.370	806,8
6	,03802	37641.	1395,8	459.8	3.062	1,534	26,97	25,08	1272,2	0.364	1229,4
7	,04466	38632.	1529.2	453.9	3.369	1,776	25,46	26,59	1715,3	0.360	1666,0
8	,05182	40351.	1674.6	451.4	3.709	2,040	24,10	28,10	2279,0	0.354	2222,5
9	,06158	41943.	1684,6	445.3	3.783	2,450	24,90	27,11	3461,9	0.346	3393,0
RUN 24											
1	,00097	31689.	1117.4	569.3	1.963	0,053	28.36	23.93	3,5	0.628	1,2
2	,00589	34780.	1339.7	567.0	2.363	0,273	25,96	26,14	54,5	0.621	43,5
3	,01163	36111.	1422.4	563.7	2.523	0,508	25.39	26,71	193,5	0.614	172,3
4	,01703	37271.	1524.8	561.3	2.717	0,719	24,44	27,75	399,1	0.607	368,6
5	.02357	38215.	1552.0	556.9	2.787	0,977	24,62	27,50	773,1	0.599	730,7
6	,02971	39074.	1604.0	553.5	2.898	1,215	24,36	27,78	1232,5	0.591	1179,1
7	,03547	40277.	1728.3	551.1	3.136	1,431	23,30	29,05	1737,0	0.584	1673,9
8	,04179	41736.	1864.0	547.8	3.402	1,672	22,39	30,22	2417,8	0.576	2343,7
9	,05040	44184.	1948.3	540.6	3.603	2,036	22,68	29,74	3805,9	0.565	3713,7

	i	X_{ti}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 25												
	1	,00109	26665.	830.5	589.6	1.409	0,059	32.11	21.16	4.3	0.682	1.6
	2	,00569	27774.	868.9	586.3	1.482	0,265	31.96	21.23	55.7	0.676	44.1
	3	,01033	28812.	907.3	583.2	1.556	0,457	31.76	21.35	169.1	0.669	148.5
	4	,01452	29886.	965.5	581.2	1.661	0,623	30.95	21.90	322.4	0.663	293.8
	5	,01964	30925.	1000.1	577.0	1.732	0,827	30.92	21.90	591.6	0.656	552.9
	6	,02435	31964.	1052.9	575.0	1.831	1,010	30.36	22.30	905.5	0.650	857.6
	7	,02890	33003.	1119.2	573.0	1.953	1,182	29.49	22.96	1261.2	0.644	1204.9
	8	,03384	34007.	1177.4	570.4	2.064	1,371	28.88	23.43	1728.5	0.637	1662.8
	9	,04088	35080.	1163.4	564.0	2.063	1,667	30.15	22.38	2712.4	0.627	2630.6

	i	X_{ti}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 26												
	1	,00179	33219.	1257.1	632.6	1.987	0,091	26.42	25.75	9.5	0.808	4.8
	2	,00705	34376.	1305.2	628.5	2.077	0,318	26.34	25.81	93.5	0.799	77.0
	3	,01172	35534.	1392.1	626.0	2.224	0,505	25.52	26.63	240.0	0.791	213.2
	4	,01646	36648.	1485.0	623.6	2.381	0,689	24.68	27.54	458.1	0.784	421.0
	5	,02235	37720.	1518.9	619.0	2.454	0,919	24.83	27.33	855.1	0.774	804.4
	6	,02779	39006.	1608.3	615.5	2.613	1,129	24.25	27.96	1327.3	0.765	1264.3
	7	,03301	40291.	1731.2	612.8	2.825	1,325	23.27	29.14	1859.6	0.757	1785.4
	8	,03837	41663.	1876.1	610.0	3.075	1,525	22.21	30.54	2500.2	0.748	2414.4
	9	,04622	43378.	1876.7	602.5	3.115	1,853	23.11	29.24	3919.3	0.735	3812.8

	i	X_{ti}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 27												
	1	,00195	33824.	1374.5	716.6	1.918	0,098	24.61	27.71	14.2	1.095	7.4
	2	,00741	35533.	1434.4	710.7	2.018	0,331	24.77	27.47	135.6	1.082	112.4
	3	,01174	36882.	1538.9	707.7	2.174	0,504	23.97	28.38	320.9	1.072	284.9
	4	,01605	38142.	1650.3	705.0	2.341	0,672	23.11	29.42	586.3	1.063	537.5
	5	,02175	39356.	1681.7	699.4	2.404	0,895	23.40	29.00	1091.9	1.049	1025.2
	6	,02651	40571.	1784.8	696.2	2.564	1.078	22.73	29.85	1622.6	1.039	1541.5
	7	,03142	41830.	1900.3	692.9	2.743	1,265	22.01	30.81	2283.0	1.028	2187.1
	8	,03651	43854.	2119.4	689.4	3.074	1.458	20.69	32.76	3096.7	1.017	2985.5
	9	,04392	44868.	2016.5	680.9	2.961	1,771	22.26	30.35	4863.6	0.999	4725.1

i	X_{ti}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 28											
1	,00667	41115.	1193.7	288.3	4.140	0,309	34.44	19,67	13,2	0.115	10.9
2	,02156	41335.	1180.8	284.3	4.153	0,905	35.00	19,33	123,9	0.112	116.6
3	,03605	41948.	1208.3	280.8	4.303	1,460	34.72	19,48	340,4	0.109	328.3
4	,05055	42562.	1243.1	277.4	4.481	2,005	34.24	19,75	662,1	0.105	645.5
5	,06589	43395.	1269.0	273.4	4.642	2,599	34.20	19,76	1145,0	0.102	1123.5
6	,08083	44403.	1333,6	269.9	4.940	3,166	33.30	20,30	1710,3	0.099	1684.5
7	,09597	45630.	1424.9	266.6	5.345	3,741	32.02	21,12	2378,0	0.095	2348.0
8	,11176	47252.	1543.7	262.9	5.871	4,355	30.61	22,09	3204,9	0.092	3170.7
9	,12995	49093.	1589,9	257.4	6.176	5,162	30.88	21,84	4624,2	0.088	4583.9
RUN 29											
1	,00534	39887.	1134.2	349.3	3.247	0,250	35.17	19,29	13,8	0.185	10.8
2	,01738	40814.	1150.2	345.0	3.334	0,738	35.48	19,08	127,8	0.181	118.4
3	,02883	41917.	1202.6	341.6	3.521	1,180	34.85	19.42	344,8	0.177	329.3
4	,04017	43240.	1286.3	338.5	3.799	1,604	33.62	20,14	655,9	0.173	634.8
5	,05266	44476.	1338.2	334.5	4.001	2,083	33.24	20,36	1143,5	0.168	1116.0
6	,06507	45844.	1418.2	330.8	4.287	2,554	32.32	20,92	1749,1	0.164	1715.4
7	,07757	46947.	1496.5	327.3	4.572	3,025	31.37	21,56	2470,4	0.159	2430.9
8	,09011	48447.	1626.2	324.1	5.018	3,494	29.79	22,72	3279,7	0.155	3234.8
9	,10506	49638.	1625.1	318.4	5.104	4,134	30.55	22,10	4745,7	0.150	4692.5
RUN 30											
1	,00554	41229.	1227.8	349.5	3.513	0,258	33.58	20.21	14,5	0.185	11.4
2	,01806	41902.	1225.8	345.0	3.554	0,760	34.18	19,82	134,9	0.180	125.2
3	,02969	42666.	1262.9	341.5	3.698	1,208	33,79	20.05	359,0	0.176	343.2
4	,04143	43564.	1315.1	338.1	3.889	1,649	33.13	20,45	691.3	0.172	669.7
5	,05413	44507.	1343.8	333.9	4.025	2,137	33,12	20.43	1203.7	0.167	1175.5
6	,06621	45585.	1418.5	330.6	4.291	2,589	32,14	21,06	1784.6	0.163	1750.6
7	,07864	46708.	1499.1	327.1	4.583	3,057	31.16	21.72	2501,9	0.159	2462.2
8	,09159	48145.	1599.7	323.4	4.947	3,554	30,10	22,49	3396,3	0.154	3350.7
9	,10648	49852.	1641.3	317.8	5.165	4.193	30.37	22,23	4875,7	0.149	4821,9

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 31												
	1	,00425	41408.	1256.0	401.6	3.127	0,202	32.97	20,60	12,7	0.262	9.3
	2	,01454	41849.	1254.0	397.5	3.154	0,622	33.37	20,32	123,4	0.256	112.4
	3	,02420	42510.	1293.7	394.4	3.280	0,992	32.86	20,64	329,4	0.251	311.4
	4	,03378	43611.	1374.3	391.6	3.510	1,349	31.73	21,38	625,8	0.246	601.2
	5	,04492	44024.	1396,3	386.9	3.609	1,777	31.96	21,20	1136,8	0.240	1103.9
	6	,05565	45813.	1458.8	383.0	3.809	2,185	31.41	21,56	1759,6	0.235	1719.2
	7	,06568	47135.	1573.1	380.1	4.139	2,559	29.96	22,61	2422,2	0.230	2375.3
	8	,07667	48324.	1672.0	376.7	4.439	2,962	28.90	23,44	3258,4	0.225	3204.5
	9	,09003	50307.	1709.3	370.3	4.617	3,534	29,43	22,95	4851,0	0.218	4786,1
RUN 32												
	1	,00239	39122.	1116.2	494.9	2.255	0,121	35.05	19,37	8,4	0.442	5.0
	2	,00970	40921.	1207.7	491.7	2.456	0,429	33.88	20,03	95,9	0.435	83,4
	3	,01752	42494.	1284,4	488.0	2.632	0,739	33.09	20,49	298,9	0.428	276,7
	4	,02515	44068.	1383.8	485.0	2.853	1,030	31.85	21,29	601,9	0.422	570,5
	5	,03377	45822.	1472.0	480.7	3.062	1,362	31.13	21,76	1096,9	0.414	1054,7
	6	,04240	47441.	1568.4	476.7	3.290	1,691	30.25	22,38	1741,2	0.407	1688,4
	7	,05091	49015.	1690.6	473.3	3.572	2,010	28.99	23,35	2497,0	0.399	2434,3
	8	,05946	50813.	1860.5	470.2	3.957	2,326	27.31	24,79	3364,3	0.392	3292.1
	9	,07060	52387.	1864.4	463.3	4.025	2,795	28,10	24,03	5106,6	0.382	5018,6
RUN 33												
	1	,00343	41473.	1377.7	541.4	2.545	0,164	30,10	22,62	17,5	0.547	11.9
	2	,01155	42100.	1356,6	535.9	2.532	0,499	31.03	21,89	159,5	0.537	141.5
	3	,01840	42996.	1413.3	532.8	2.653	0,765	30.42	22,33	388,8	0.530	360.6
	4	,02523	43981.	1487.0	529.9	2.806	1,021	29.58	22,97	714,4	0.522	676.3
	5	,03346	45101.	1512.3	524.7	2.882	1,340	29,82	22,74	1290,6	0.513	1239.7
	6	,04094	46444.	1602.9	521.2	3.076	1,621	28.98	23.40	1933,1	0.505	1871,2
	7	,04841	48012.	1733,2	517.9	3.346	1,898	27.70	24,48	2686,6	0.497	2614.0
	8	,05646	50027.	1897,3	514.0	3.691	2,202	26.37	25,70	3678,0	0.489	3593.7
	9	,06692	52177.	1932.8	506.4	3.817	2,647	27.00	25,02	5621,6	0.477	5518.5

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 34												
	1	,00280	40880.	1204.0	536.3	2.245	0,138	33.95	20,03	12,7	0.537	8.0
	2	,01033	42351.	1259.6	531.9	2.368	0,452	33.62	20,20	128,5	0.528	112,6
	3	,01750	44135.	1360.5	528.5	2.574	0,733	32.44	20,93	352,2	0.520	325,7
	4	,02471	45784.	1469.6	525.3	2.797	1,007	31.15	21,79	687,3	0.513	650.3
	5	,03323	47478.	1540.4	520.3	2.961	1,337	30.82	21,99	1270,0	0.503	1220.0
	6	,04148	49039.	1629.3	516.0	3.157	1,652	30.10	22,50	2001,2	0.495	1938.8
	7	,04930	50688.	1771.2	512.8	3.454	1,942	28.62	23,67	2796,4	0.487	2723,1
	8	,05758	52159.	1897,3	509.2	3.726	2,252	27.49	24,64	3808,0	0.478	3723,1
	9	,06857	54388.	1931.9	501.2	3,854	2,722	28.15	23,97	5903,5	0.466	5799,1
RUN 35												
	1	,00128	34730.	975,6	570.4	1.710	0,069	35.60	19,06	5,0	0.631	2.1
	2	,00661	36111.	1043,1	567.8	1,837	0,303	34.62	19,60	67,6	0.624	55,2
	3	,01210	37492.	1116,1	565.2	1.975	0,525	33.59	20,20	207,6	0.617	185,6
	4	,01750	38874.	1204,2	563.1	2.139	0,735	32.28	21,02	416,4	0.611	385,2
	5	,02462	40255.	1241,6	558.0	2.225	1,016	32,42	20,89	841,1	0.601	796,7
	6	,03110	41557.	1305.9	554.4	2.355	1,266	31,82	21,27	1347,6	0.593	1291,7
	7	,03716	42939.	1405,2	551.9	2.546	1,492	30,56	22,16	1898,6	0.586	1832,5
	8	,04374	44280.	1493,7	548.7	2,722	1,741	29,64	22,84	2631,7	0.578	2554,3
	9	,05282	45780.	1483,5	541.1	2.742	2,126	30,86	21,86	4180,0	0.565	4083,3
RUN 36												
	1	,00227	41282.	1411.2	578.0	2.442	0,113	29.25	23,28	10,7	0.643	6,1
	2	,00934	42494.	1455,7	573.4	2.539	0,409	29.19	23,30	122,9	0.633	105,9
	3	,01621	43570.	1509,0	569.4	2.650	0,679	28.87	23,54	354,2	0.624	325,1
	4	,02258	44872.	1617.6	566.6	2.855	0,920	27.74	24,50	668,5	0.616	628,5
	5	,03020	45769.	1635,6	561.6	2.912	1,213	27,98	24,26	1217,7	0.606	1164,0
	6	,03742	47115.	1724,6	557.7	3.093	1,486	27,32	24,83	1880,0	0.597	1813,6
	7	,04442	48282.	1828.1	554.4	3.298	1,746	26,41	25,68	2637,1	0.588	2558,9
	8	,05145	49494.	1955.3	551,3	3.547	2,004	25,31	26,80	3505,9	0.580	3416,3
	9	,06109	50705.	1903,5	543.5	3.502	2,409	26,64	25,38	5356,2	0.567	5246,5

RUN 37

i	X_{Li}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
1	.00325	40973.	1364.8	598.1	2.282	0.155	30.02	22.72	19.7	0.696	13.0
2	.01081	42464.	1394.3	591.9	2.356	0.466	30.46	22.35	172.7	0.684	151.7
3	.01699	43819.	1486.5	588.8	2.525	0.704	29.48	23.08	408.5	0.676	375.9
4	.02323	45265.	1599.4	585.8	2.730	0.938	28.30	24.04	745.8	0.667	701.8
5	.03091	46575.	1637.7	580.3	2.822	1.234	28.44	23.89	1355.1	0.656	1296.1
6	.03809	48156.	1739.5	576.1	3.019	1.506	27.68	24.52	2077.5	0.646	2004.9
7	.04520	49692.	1863.0	572.4	3.255	1.772	26.67	25.44	2931.5	0.636	2845.8
8	.05224	51047.	1998.4	569.0	3.512	2.031	25.54	26.56	3894.9	0.627	3796.7
9	.06180	52447.	1965.3	561.1	3.503	2.432	26.69	25.34	5899.6	0.613	5779.9

RUN 38

i	X_{Li}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
1	.00102	39833.	1197.9	646.2	1.854	0.055	33.25	20.45	4.9	0.854	1.7
2	.00578	41285.	1301.1	644.4	2.019	0.264	31.73	21.45	67.4	0.846	53.1
3	.01112	42694.	1394.9	641.6	2.174	0.478	30.61	22.23	222.8	0.837	196.4
4	.01647	44146.	1507.1	639.1	2.358	0.683	29.29	23.24	467.1	0.828	428.5
5	.02342	45555.	1550.9	633.5	2.448	0.953	29.37	23.13	959.2	0.816	904.0
6	.02995	47095.	1637.0	629.1	2.602	1.203	28.77	23.60	1583.1	0.804	1512.5
7	.03589	48416.	1755.1	626.2	2.803	1.422	27.59	24.61	2245.9	0.795	2162.3
8	.04233	49824.	1869.6	622.5	3.003	1.662	26.65	25.47	3127.5	0.784	3029.3
9	.05141	51277.	1824.6	613.6	2.974	2.043	28.10	24.06	5047.5	0.767	4923.8

RUN 39

i	X_{Li}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
1	.00302	41442.	1444.2	609.6	2.369	0.144	28.70	23.79	18.0	0.728	11.5
2	.01030	42831.	1476.3	603.8	2.445	0.444	29.01	23.48	161.7	0.716	140.9
3	.01655	44359.	1582.5	600.3	2.636	0.685	28.03	24.29	399.7	0.707	366.7
4	.02281	45795.	1699.8	597.2	2.846	0.920	26.94	25.27	742.6	0.698	697.8
5	.03054	47230.	1743.8	591.4	2.949	1.218	27.09	25.09	1370.2	0.686	1309.5
6	.03762	48619.	1838.4	587.2	3.131	1.484	26.45	25.68	2095.5	0.676	2020.9
7	.04443	50009.	1972.3	583.8	3.378	1.736	25.36	26.78	2908.8	0.667	2821.4
8	.05159	51398.	2105.3	580.0	3.630	2.002	24.41	27.81	3928.4	0.657	3827.5
9	.06131	52926.	2058.5	571.5	3.602	2.412	25.71	26.31	6060.0	0.642	5935.9

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 40											
1	,00189	41073.	1335,4	656.7	2.034	0,096	30.76	22,15	11,1	0.883	5,7
2	,00760	42398.	1405,1	652.9	2.152	0,337	30.17	22,56	113,1	0.873	94,1
3	,01313	43723.	1493,9	649.7	2,299	0,556	29.27	23,26	314,8	0.863	282.7
4	,01873	44916.	1583,1	646.6	2.448	0,769	28.37	23,99	621,0	0.853	575.8
5	,02577	46152.	1608,4	640.7	2.510	1,043	28,69	23,67	1205,1	0.840	1142.3
6	,03229	47477.	1678,3	636.2	2.638	1,293	28,29	23,99	1914,9	0.828	1836,0
7	,03828	48670.	1781,8	633.1	2,815	1,515	27.31	24,84	2670,8	0.818	2578,1
8	,04450	49906.	1891,6	629.7	3,004	1,745	26.38	25,72	3598,4	0.808	3491.4
9	,05342	51275.	1840.6	620.8	2.965	2,122	27.86	24,27	5671,2	0.791	5538,1
RUN 41											
1	,00276	40204.	1341,3	681.1	1.969	0,132	29,97	22,79	20,3	0.958	12.4
2	,00933	41831.	1382,4	674.7	2.049	0,404	30.26	22,52	174,9	0.944	150,1
3	,01461	43550.	1499,7	671.5	2.233	0,609	29.04	23,46	408,4	0.934	370,2
4	,02028	45223.	1612,8	667.8	2.415	0,825	28.04	24,29	774,2	0.923	721.7
5	,02726	46943.	1672,6	661.6	2.528	1,096	28.07	24,21	1441,3	0.909	1369.8
6	,03339	48570.	1788,6	657.5	2.720	1,327	27.16	25,01	2172,2	0.897	2084.8
7	,03948	50290.	1939,8	654.0	2.966	1,554	25.92	26,19	3032,8	0.885	2930,0
8	,04575	52056.	2113,3	650.3	3,250	1,787	24.63	27,56	4072,6	0.874	3954,2
9	,05492	53775.	2065,8	640.6	3.225	2,176	26.03	25,97	6465,4	0.855	6317,6
RUN 42											
1	,00925	45355.	1179.4	247.1	4.774	0,414	38.46	17,63	16,1	0.078	14.0
2	,02940	46069.	1181,0	242.3	4.874	1,204	39.01	17,35	153,8	0.075	147,1
3	,04937	46872.	1201.5	237.9	5.050	1,968	39.01	17,33	436,2	0.072	425,1
4	,06907	47855.	1250.5	233.9	5.345	2,714	38,27	17,66	848,7	0.069	833.5
5	,08956	48881.	1291,5	229.6	5.626	3,511	37.85	17,85	1442,5	0.066	1423,1
6	,11017	50087.	1355,2	225.4	6.013	4,322	36.96	18,28	2183,7	0.063	2160.3
7	,13129	51560.	1440.6	221.1	6.517	5,172	35.79	18,87	3097,1	0.060	3069.9
8	,15256	53122.	1560,5	217.0	7.192	6,027	34.04	19,86	4099,7	0.057	4069.2
9	,17618	54952.	1623.7	211.4	7.680	7,121	33.84	19,94	5738,3	0.054	5703.1

	i	X_{ti}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_6/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 43												
	1	,00696	45100.	1188.0	305.1	3.894	0,317	37,96	17,88	15,5	0.132	12,8
	2	,02243	45993.	1208.2	300.6	4.019	0,928	38,07	17,81	145,4	0.128	136,9
	3	,03761	46886.	1246.8	296.7	4.203	1,501	37,60	18,02	402,5	0.124	388,5
	4	,05272	47779.	1298.1	293.0	4.430	2,062	36,81	18,41	780,3	0.120	761,1
	5	,06895	48851.	1332.7	288.5	4.620	2,683	36,66	18,47	1361,3	0.116	1336,3
	6	,08524	50012.	1383.0	284.1	4.868	3,313	36,16	18,71	2107,1	0.112	2076,5
	7	,10138	51218.	1459.9	280.1	5.211	3,931	35.08	19,29	2961,2	0.108	2925,6
	8	,11746	52513.	1569.7	276.6	5.676	4,538	33.45	20,25	3882,7	0.104	3842,6
	9	,13601	54031.	1601.2	270.8	5.912	5,350	33,74	20,03	5502,4	0.100	5455,7
RUN 44												
	1	,00723	46874.	1295.3	319.4	4.055	0,328	36,19	18,76	18,6	0.148	15.4
	2	,02290	47329.	1273.7	314.3	4.053	0,948	37,16	18,24	171,9	0.143	162,1
	3	,03750	47784.	1293.0	310.4	4.166	1,501	36,96	18,33	452,8	0.139	437,1
	4	,05184	48330.	1331.6	306.9	4.339	2,031	36,29	18,67	849,5	0.135	828,3
	5	,06739	49377.	1364,5	302.3	4.514	2,628	36,19	18,71	1466,2	0.130	1438,7
	6	,08264	50515.	1427.8	298.2	4.788	3,208	35,38	19,13	2205,0	0.126	2171,8
	7	,09796	51971.	1529.0	294.4	5.194	3,788	33,99	19,92	3066,0	0.122	3027,5
	8	,11385	53700.	1654,2	290.3	5.698	4,402	32,46	20,86	4114,2	0.118	4070,3
	9	,13216	55635.	1721.8	284.2	6.058	5,211	32,46	20,81	5916,1	0.113	5864,6
RUN 45												
	1	,00590	45506.	1217,7	349.2	3.487	0,272	37.37	18,17	16,0	0.185	12,7
	2	,01939	46301.	1227.5	344.6	3.563	0,811	37,72	17,97	153,2	0.179	142,9
	3	,03213	47273.	1279.0	341.0	3.751	1,293	36,96	18,34	409,4	0.175	392,7
	4	,04462	48289.	1353,7	337.6	4.007	1,752	35,67	19,02	767,0	0.170	744,3
	5	,05876	49482.	1391,3	333.1	4.177	2,291	35,57	19,05	1361,9	0.165	1332,1
	6	,07291	51250.	1480.3	328.7	4.505	2,832	34,61	19,57	2122,9	0.160	2086,2
	7	,08674	52796.	1596.9	325.0	4.913	3,348	33.06	20,49	2963,7	0.156	2920,9
	8	,10116	54651.	1741.3	321.0	5.424	3,894	31.39	21,59	3996,6	0.151	3947,7
	9	,11820	56616.	1798.6	314.5	5.718	4,638	31,59	21,39	5862,2	0.145	5804,1

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Frg_i
RUN 46											
1	,00533	45261.	1224.8	376.4	3.254	0,247	36,95	18,39	15,8	0.222	12,3
2	,01787	46157.	1234.0	371.5	3.322	0,751	37.40	18,13	155,4	0.216	144.0
3	,02971	47322.	1289.2	367.7	3.506	1,202	36,71	18,47	420.0	0.211	401,4
4	,04132	48443.	1362.3	364.4	3.739	1,631	35,56	19,08	794,6	0.206	769,3
5	,05441	49742.	1404.7	359.6	3.907	2,132	35,41	19,13	1411,7	0.200	1378,2
6	,06718	51087.	1476.3	353.4	4.154	2,615	34,60	19,57	2163,9	0.195	2123.0
7	,08012	52655.	1575.3	351.4	4.483	3,106	33,43	20,26	3078,3	0.189	3030.1
8	,09340	54448.	1702.5	347.3	4.902	3,613	31,98	21,17	4174,1	0.184	4118,8
9	,10880	56375.	1754.6	341.0	5.145	4,274	32,13	21,02	6030,5	0.178	5965,2
RUN 47											
1	,00504	45209.	1244.3	410.3	3.033	0,235	36.33	18,70	17,8	0.276	13.7
2	,01654	46340.	1262.8	405.1	3.117	0,701	36,70	18,48	167,6	0.269	154,4
3	,02716	47696.	1334.0	401.5	3.323	1,107	35,76	18,96	439,9	0.263	418,7
4	,03794	48871.	1402.4	397.9	3.525	1,511	34,85	19,45	847,1	0.257	817,9
5	,05015	50409.	1450.6	392.6	3.694	1,985	34,75	19,47	1529,4	0.251	1490,5
6	,06186	51765.	1522.3	388.4	3.919	2,432	34,00	19,89	2345,6	0.244	2298,0
7	,07313	53709.	1680.3	385.1	4.363	2,846	31,96	21,18	3210,6	0.239	3155,5
8	,08487	55156.	1813.1	381.6	4.751	3,281	30,42	22,26	4254,8	0.233	4192,1
9	,09951	56738.	1808.3	374.5	4.828	3,920	31.38	21,51	6352,6	0.225	6277,2
RUN 48											
1	,00304	45790.	1265.8	497.2	2.546	0,149	36.18	18,80	12.0	0.444	7.8
2	,01176	46974.	1313.3	493.0	2.664	0,508	35.77	19.00	134,2	0.436	119.3
3	,02041	48341.	1384.2	489.2	2.829	0,842	34.92	19,45	388,2	0.428	362.8
4	,02834	49753.	1430.7	486.1	3.046	1,157	33.60	20,22	754,6	0.421	719.4
5	.03886	51257.	1550.0	480.7	3.183	1,541	33.50	20,25	1407,6	0.412	1359.9
6	,04854	52652.	1614.7	476.1	3.391	1,909	32,73	20,71	2221,7	0.404	2162.2
7	,05784	54446.	1738.9	472.0	3.680	2,252	31,31	21,65	3126,4	0.396	3056.4
8	,06764	56260.	1882.1	468.6	4.017	2,619	29,90	22,67	4271,4	0.388	4190.4
9	.08003	58319.	1908.0	460.8	4.142	3,149	30,56	22,10	6503,6	0.377	6405.0

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 49												
	1	,00290	45748.	1297.4	514.3	2.522	0,142	35.26	19.29	12,0	0.483	7.7
	2	,01118	46566.	1327.6	510.3	2.602	0,483	35.07	19.38	131,2	0.474	115.9
	3	,01923	47702.	1392.9	506.9	2.748	0,794	34.25	19,84	369,8	0.467	344.0
	4	,02711	48838.	1476.1	503.9	2.929	1,087	33.09	20,55	713,6	0.459	677,8
	5	,03686	50428.	1521.6	498.1	3.055	1,463	33.14	20,47	1363,5	0.450	1314,5
	6	,04636	52109.	1597.1	493.1	3.239	1,828	32,63	20,77	2206,6	0.441	2144.7
	7	,05510	53790.	1730.9	489.7	3.536	2,150	31,08	21,81	3081,2	0.433	3008,6
	8	,06428	55879.	1906.3	486.0	3.923	2,490	29.31	23.13	4168,6	0.424	4084.9
	9	,07626	58060.	1941.2	478.0	4.061	3,000	29.91	22,59	6388,4	0.413	6286,1
RUN 50												
	1	,00380	46978.	1320.3	507.1	2.604	0,180	35,58	19,14	17,4	0.463	12.2
	2	,01309	48848.	1392.2	502.0	2.773	0,557	35.09	19.38	167,6	0.454	150.6
	3	,02193	50027.	1493.1	498.1	2.998	0,894	33.91	20.05	454,2	0.446	426.2
	4	,03080	52132.	1593.3	494.4	3.223	1,224	32,72	20,78	880,3	0.438	841.5
	5	,04104	53409.	1628.1	488.8	3.331	1,615	32,80	20,69	1606,9	0.428	1554,9
	6	,05078	54503.	1683.6	484.2	3.477	1,983	32,37	20,95	2485,4	0.420	2421.2
	7	,06016	55689.	1779.2	480.5	3.703	2,328	31.30	21,67	3459,2	0.411	3384.2
	8	,06970	57012.	1896.2	476.8	3.977	2,678	30.07	22,57	4603,4	0.403	4517,6
	9	,08207	58380.	1858.3	466.7	3.965	3,209	31,42	21,52	6970,6	0.392	6866.5
RUN 51												
	1	,00247	46937.	1367.2	581.3	2.352	0,122	34.33	19,84	12,2	0.652	7.2
	2	,00989	48555.	1449.8	577.1	2.512	0,429	33.49	20.32	136,1	0.642	118,1
	3	,01747	50174.	1540.6	573.0	2.689	0,723	32.57	20,89	404,8	0.632	373.4
	4	,02490	51792.	1655.8	569.5	2.908	1,002	31.28	21,75	803,2	0.622	759.2
	5	,03357	53180.	1706.7	563.9	3.026	1,332	31.16	21.80	1489,6	0.611	1429,9
	6	,04194	54567.	1784.9	559.2	3.192	1,648	30.57	22.20	2350,9	0.600	2276,4
	7	,05005	55954.	1896.0	555.3	3.414	1,949	29.51	23,00	3337,7	0.590	3249.6
	8	,05846	57110.	1985.4	551.1	3.603	2,263	28.76	23.59	4567,5	0.579	4465.2
	9	,06944	58260.	1915.8	542.3	3.533	2,731	30.41	22,22	7064,7	0.564	6939.0

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Bi}	Fr_{gi}
RUN 52											
1	,00304	46234.	1425.7	619.5	2.301	0,145	32.43	21.06	18,8	0.756	12.0
2	,01073	47608.	1459.3	613.5	2.379	0,459	32.62	20.90	178,5	0.744	156.2
3	,01758	49027.	1542.6	607.7	2.539	0,721	31.78	21.44	459,1	0.733	423.2
4	,02456	50583.	1643.4	605.8	2.713	0,983	30.78	22.13	883,3	0.723	833.5
5	,03276	51956.	1681.5	599.8	2.804	1,296	30.90	22.00	1614,5	0.710	1547.5
6	,04038	53330.	1760.7	595.2	2.958	1,582	30.29	22.43	2475,9	0.698	2393.4
7	,04780	54795.	1875.6	591.3	3.172	1,856	29.21	23.25	3464,5	0.688	3367.6
8	,05523	56305.	2016.6	587.7	3.431	2,128	27.92	24.33	4597,1	0.677	4486.2
9	,06580	57079.	1943.9	578.1	3.363	2,580	29.67	22.80	7214,9	0.660	7077.5
RUN 53											
1	,00302	47224.	1496,8	639.8	2.339	0,144	31.55	21,65	20,1	0.819	12.8
2	,01063	48627.	1531.4	633.6	2.417	0,455	31.75	21.47	190,0	0.806	166.0
3	,01738	50029.	1616.6	629.6	2.567	0,714	30.95	22.02	487,1	0.795	448.6
4	,02404	51432.	1720.3	626.1	2.748	0,962	29.90	22.79	913,8	0.784	861.0
5	,03195	52928.	1777.3	620.2	2.866	1,263	29.78	22.84	1649,7	0.771	1579.2
6	,03948	54424.	1868.3	615.4	3.036	1,547	29.13	23.33	2548,4	0.758	2461.2
7	,04691	55874.	1980.0	611.2	3.240	1,823	28.22	24.07	3610,8	0.747	3507.7
8	,05441	57370.	2113.2	607.1	3.481	2,101	27.15	25.02	4862,5	0.735	4743.6
9	,06483	58913.	2048.7	597.2	3.430	2,547	28.76	23.52	7634,4	0.717	7487.2
RUN 54											
1	,01369	50781.	1136.4	196.4	5.787	0,596	44.69	15,15	20,0	0.044	18.2
2	,04271	51010.	1119.4	191.2	5.855	1,721	45.57	14.83	189,7	0.042	184.1
3	,07142	51605.	1131.5	186.3	6.072	2,823	45.61	14,81	534,1	0.039	525.0
4	,09975	52382.	1169.5	181.9	6.430	3,914	44.79	15,08	1029,1	0.037	1016.8
5	,12869	53526.	1218.3	177.1	6.878	5,081	43.94	15.37	1717,7	0.035	1702.3
6	,15882	54896.	1275.9	172.1	7.412	6,339	43.03	15.69	2623,7	0.032	2605.4
7	,18971	56728.	1357.0	166.9	8.128	7,712	41.80	16.14	3777,2	0.030	3756.0
8	,22089	58970.	1498.2	162.0	9.246	9,112	39.36	17.16	4997,5	0.028	4974.0
9	,25497	61075.	1568.3	155.8	10.065	10,925	38.94	17.31	7001,7	0.025	6975.2

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RLN 55											
1	,00841	49582.	1153.0	270.5	4.263	0,382	43.00	15,75	17,4	0.098	14.9
2	,02698	50119.	1174.3	266.3	4.409	1,109	42.68	15,86	161,8	0.095	154.0
3	,04588	51014.	1211.4	262.1	4.622	1,823	42.11	16,07	460,8	0.091	448.0
4	,06507	51909.	1250.1	257.8	4.850	2,546	41.52	16,30	923,5	0.088	905.6
5	,08529	53162.	1288.4	252.6	5.096	3,335	41.26	16,38	1623,6	0.084	1600.4
6	,10566	54594.	1346.7	248.0	5.430	4,143	40.54	16,66	2526,2	0.080	2497.8
7	,12615	56384.	1445.1	243.5	5.935	4,959	39.02	17,31	3584,8	0.076	3551.8
8	,14682	58263.	1578.7	239.2	6.599	5,778	36.91	18,32	4744,3	0.073	4707.2
9	,17021	60322.	1640.8	233.0	7.041	6,863	36,76	18,35	6758,1	0.069	6715.0
RLN 56											
1	,00589	51444.	1187.1	312.9	3.794	0,280	43.34	15,59	13,8	0.143	11.2
2	,02098	51976.	1234.1	309.7	3.985	0,884	42.12	16,06	146,5	0.139	137.6
3	,03722	52866.	1274,5	305.5	4.171	1,505	41.48	16,31	449,8	0.134	434.4
4	,05329	53888.	1337.4	301.7	4.432	2,103	40.29	16,80	899,9	0.130	878.4
5	,07055	54821.	1369,0	296.9	4.611	2,765	40.04	16,89	1597,7	0.125	1569.6
6	,08797	55976.	1418,2	292.2	4.854	3,442	39.47	17,12	2509,2	0.120	2474.6
7	,10532	57264.	1494.0	287.8	5.191	4,115	38.33	17,63	3575,6	0.116	3535.0
8	,12271	58641.	1596,3	283.7	5.628	4,786	36.73	18,41	4760,6	0.111	4714.7
9	,14283	60641.	1641,9	277.1	5.925	5,696	36.93	18,26	6910,1	0.106	6856,1
RLN 57											
1	,00642	50363.	1332,0	369.1	3.609	0,291	37.81	17,99	20.6	0.211	16.6
2	,02050	51535.	1358.3	363.9	3.733	0,847	37.94	17,90	188,1	0.205	175.9
3	,03391	52706.	1419.6	359.6	3.946	1,350	37.13	18,28	503,4	0.199	483.6
4	,04738	53971.	1499.0	355.9	4.212	1,846	36.00	18,86	967,6	0.193	940.4
5	,06228	55517.	1554.5	350.5	4.435	2,414	35.71	18,98	1719,2	0.187	1683.5
6	,07722	57157.	1633.3	345.5	4.728	2,989	34.99	19,36	2691,6	0.181	2647.6
7	,09195	58796.	1748,2	341.1	5.126	3,547	33.63	20,14	3802,4	0.176	3750.9
8	,10673	60670.	1914,7	337.0	5.682	4,103	31.69	21,39	5038,1	0.170	4979.7
9	,12425	62404.	1937.7	330.0	5.872	4,872	32.21	20,98	7329,6	0.163	7260.6

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 58											
1	,00659	51352.	1276,0	374.0	3.414	0,300	40.22	16,89	23,0	0.219	18.7
2	,02089	52125.	1273,1	368.3	3.456	0,870	40.94	16,56	210,9	0.212	197.7
3	,03409	53264.	1329.3	364.3	3.649	1,369	40.07	16,92	548,4	0.207	527.4
4	,04732	54629.	1409.7	360.5	3.910	1,858	38,75	17,50	1037,4	0.201	1008,8
5	,06192	56223.	1471,2	355.4	4.140	2,416	38.22	17.72	1813,6	0.195	1776,2
6	,07622	57816.	1562.4	351.0	4.452	2,956	37.00	18,30	2745,9	0.189	2700.5
7	,09108	59546.	1662.9	346.2	4.803	3,527	35.81	18,90	3941,2	0.183	3887.7
8	,10612	61139.	1772.4	341.6	5.188	4,109	34.49	19,62	5339,1	0.177	5277.8
9	,12343	62624.	1792,8	334.6	5.357	4,875	35.04	19,26	7760,9	0.170	7688.5
RUN 59											
1	,00568	52362.	1285,4	387.2	3.320	0,263	40.74	16,67	19,3	0.239	15.2
2	,01860	53277.	1322.5	382.9	3.454	0,775	40.28	16,85	177,4	0.233	164.8
3	,03165	54420.	1377.1	378.7	3.637	1,268	39.52	17.17	500,8	0.226	479.8
4	,04496	55792.	1447,8	374.4	3.867	1,762	38.54	17,61	1002,1	0.220	972.6
5	,05934	56844.	1473,3	369.0	3.993	2,311	38,58	17,56	1790,2	0.213	1751.3
6	,07348	58079.	1529,1	364.1	4.199	2,850	37.98	17,83	2774,3	0.207	2726.6
7	,08754	59588.	1621.3	359.7	4.507	3,384	36,75	18,43	3927,6	0.201	3871,6
8	,10197	61280.	1733.1	355.1	4.880	3,938	35.36	19,15	5317,5	0.194	5253.3
9	,11870	62195.	1696.9	348.0	4.876	4,676	36,65	18,42	7768,8	0.187	7692,8
RUN 60											
1	,00472	50963.	1241.6	392.6	3.162	0,224	41.04	16,53	14,8	0.248	11.2
2	,01686	51767.	1278.3	388.7	3.289	0,712	40,50	16,75	155,8	0.242	143.8
3	,02954	53552.	1360.4	384.4	3.539	1,197	39,36	17,22	467,2	0.236	446,5
4	,04217	54891.	1436.7	380.4	3.777	1,667	38,21	17.75	936,6	0.230	907,5
5	,05591	56229.	1487.0	375.4	3.961	2,191	37,81	17,91	1675,2	0.223	1636,7
6	,06945	57568.	1558,7	370.8	4.203	2,703	36,93	18,33	2593,4	0.217	2546,2
7	,08313	58907.	1642,5	366.5	4.482	3,221	35.86	18,88	3707,0	0.210	3651.4
8	,09686	60246.	1744.7	362.3	4.916	3,739	34.53	19,61	4977,7	0.204	4914,1
9	,11316	61495.	1727.3	355.1	4.864	4,454	35.60	18,96	7339,4	0.197	7263,7

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 61												
	1	,00577	51077.	1302.0	412.4	3.157	0,265	39.23	17,33	22,7	0.279	17.9
	2	,01828	52375.	1336,0	407.1	3.281	0,764	39.20	17,31	201,4	0.271	186.9
	3	,03139	53395.	1343.6	401.4	3.348	1,273	39.74	17,04	604,0	0.264	579.0
	4	,04360	54693.	1404.7	397.0	3.538	1,735	38.94	17,39	1161,8	0.257	1127.5
	5	,05665	56083.	1452.9	391.9	3.707	2,238	38.60	17,52	2005,6	0.250	1961.1
	6	,06977	57937.	1540.7	387.0	3.981	2,747	37.60	17,97	3089,1	0.243	3034.5
	7	,08197	59791.	1695.4	383.7	4.418	3,190	35.27	19,18	4122,8	0.237	4060.5
	8	,09533	61645.	1830.6	379.3	4.826	3,701	33.68	20,09	5550,0	0.230	5478.8
	9	,11115	63267.	1838,3	372.0	4.942	4,400	34.42	19,60	8154,4	0.222	8069.6
RUN 62												
	1	,00396	51969.	1338,3	453.1	2.954	0,189	38.83	17,50	15,0	0.353	10.8
	2	,01437	52807.	1380,4	449.2	3.073	0,610	38,25	17,76	157,2	0.346	142,8
	3	,02509	53970.	1439.2	445.0	3.234	1,019	37.50	18,11	462,8	0.338	438,2
	4	,03572	55179.	1515,9	441.3	3.435	1,413	36.40	18,66	918,6	0.331	884,0
	5	,04785	56296.	1537,4	435.6	3.530	1,877	36,62	18,52	1699,2	0.322	1652,7
	6	,05981	57692.	1593.2	430.3	3.702	2,335	36,21	18,71	2710,9	0.314	2652.9
	7	,07141	59088.	1679,9	426.0	3.944	2,773	35.17	19,25	3865,3	0.306	3796.8
	8	,08273	60483.	1801.3	422.3	4.265	3,188	33,58	20,18	5089,5	0.299	5011.8
	9	,09688	62112.	1807,5	414.8	4.358	3,798	34,36	19,66	7539,1	0.289	7446,0
RUN 63												
	1	,00457	49544.	1275,2	503.5	2.533	0,212	38,85	17,54	23,2	0.454	17.2
	2	,01488	50940.	1298,3	497.3	2.611	0,626	39,23	17,33	210,7	0.444	191.8
	3	,02391	53033.	1413,2	493.7	2.863	0,967	37,53	18,12	524,6	0.436	494.8
	4	,03342	55359.	1549.5	489.7	3.164	1,320	35,73	19,03	1010,8	0.428	969,6
	5	,04457	57685.	1642.6	483.5	3.397	1,747	35,12	19,32	1861,4	0.417	1806,0
	6	,05496	59546.	1761,9	479.1	3.678	2,134	33,80	20,07	2834,5	0.408	2766,9
	7	,06561	61872.	1934.3	474.6	4.076	2,531	31,99	21,21	4039,1	0.399	3959,2
	8	,07619	62244.	1977.2	470.6	4.202	2,921	31,48	21,55	5392,5	0.390	5301.1
	9	,08970	66571.	2201.9	462.2	4.764	3,499	30.23	22,36	8128.1	0.378	8017.6

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 64												
	1	,00298	47687.	1138.2	515.4	2.208	0,146	41.90	16.22	12,8	0.486	8.3
	2	,01144	49741.	1227.5	511.6	2.400	0,495	40.52	16.77	139,2	0.478	123.4
	3	,02007	52023.	1342.4	507.9	2.643	0,828	38.75	17,53	408,1	0.470	380.9
	4	,02897	54076.	1458.3	504.2	2.892	1,161	37.08	18,32	831,9	0.461	793.2
	5	,03950	56130.	1532.0	498.2	3.075	1,565	36.64	18,51	1593,8	0.451	1540.7
	6	,04955	58411.	1659.4	493.5	3.362	1,945	35.20	19,25	2529,8	0.441	2463.4
	7	,05958	60003.	1766.1	489.2	3.610	2,320	33.98	19,94	3652,9	0.432	3573.8
	8	,06961	62062.	1935.8	485.3	3.987	2,689	32.06	21,14	4928,0	0.423	4837.2
	9	,08265	63837.	1933.5	476.8	4.056	3,250	33.04	20,44	7602,5	0.410	7491.2
RUN 65												
	1	,00431	51091.	1263,7	486.1	2.599	0,201	40.43	16,86	19,2	0.416	14,0
	2	,01467	52821.	1323,5	481.0	2.752	0,615	39,91	17,05	183,9	0.407	167.0
	3	,02466	54924.	1430,6	476.8	3.000	0,992	38,39	17,72	503,2	0.399	475.2
	4	,03488	56794.	1537.4	472.7	3.252	1,369	36,94	18,42	992,1	0.390	953,1
	5	,04652	58851.	1618.2	466.8	3.467	1,810	36.37	18,68	1816,1	0.381	1763,9
	6	,05776	60767.	1728.4	461.9	3.742	2,230	35.16	19,31	2818,8	0.372	2754,5
	7	,06894	62637.	1864.4	457.6	4.075	2.643	33.60	20.21	3998,2	0.363	3922.3
	8	,08058	64600.	2015.3	452.9	4.450	3,078	32.06	21,18	5463,1	0.354	5375,5
	9	,09495	66657.	2030.1	444.3	4.569	3,698	32.83	20,60	8291,7	0.342	8185,5
RUN 66												
	1	,00371	48480.	1375,5	544.4	2.527	0,174	35.25	19,35	19,4	0.550	13.4
	2	,01275	50214.	1433.3	538.8	2.660	0,540	35,04	19,43	184,4	0.540	164.9
	3	,02138	51584.	1495,8	534.2	2.800	0,870	34,49	19,73	505,4	0.530	473,2
	4	,02977	52953.	1580.9	530.4	2.981	1,182	33,50	20,31	964,9	0.521	920.6
	5	,03911	54414.	1641.8	525.1	3.127	1,536	33.14	20.50	1695,4	0.511	1637.1
	6	,04831	56149.	1744.4	520.5	3.352	1,881	32.19	21,09	2610,9	0.501	2539.1
	7	,05751	57747.	1858.6	516.2	3.601	2,223	31.07	21,85	3706,4	0.491	3621.6
	8	,06658	59344.	2005.7	512.4	3.914	2,555	29.59	22,95	4922,4	0.482	4825,5
	9	,07884	61390.	2004.3	503.4	3.981	3,082	30.63	22,07	7605,9	0.468	7487,1

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 67											
1	,00449	53143.	1436,0	533.5	2.692	0,207	37.01	18,44	25,2	0.522	18.5
2	,01461	54294.	1451,0	527.2	2.752	0,611	37.42	18,20	226,3	0.511	205,3
3	,02348	55444.	1521,2	523.5	2.906	0,944	36.45	18,68	563,0	0.502	529,9
4	,03207	56824.	1605.1	519.4	3.090	1,282	35.40	19.23	1074,0	0.493	1028,5
5	,04335	58205.	1635.4	513.1	3.188	1,688	35.59	19,10	1958,0	0.481	1897,1
6	,05335	59585.	1707,5	508.2	3.360	2,062	34.90	19,46	2992,5	0.471	2917,9
7	,06331	61195.	1813.8	503.7	3.601	2,432	33.74	20,12	4222,6	0.461	4134,8
8	,07312	63036.	1972.0	499.8	3.946	2,789	31.97	21,25	5566,8	0.452	5467,0
9	,08598	65106.	1988,6	491.0	4.050	3,339	32.74	20,67	8403,3	0.438	8282,4
RUN 68											
1	,00496	50953.	1290.0	552.2	2.336	0,230	39.50	17,22	35,2	0.576	26.8
2	,01394	53172.	1377.1	546.9	2.518	0,593	38.61	17.60	240,8	0.565	218,0
3	,02076	54929.	1537,9	546.0	2.817	0,843	35.72	19,06	491,5	0.558	459.0
4	,03010	56409.	1600.5	540.7	2.960	1,195	35.25	19,30	1037,1	0.547	990,0
5	,04048	58027.	1638.0	534.0	3.068	1,595	35.43	19.16	1953,4	0.535	1889,3
6	,04942	59045.	1755.2	530.1	3.311	1,924	33,98	19,98	2882,3	0.525	2805,0
7	,05898	61079.	1848.5	525.5	3.517	2,281	33,04	20,54	4120,6	0.514	4029,1
8	,06832	62512.	1973.3	521.6	3.783	2,623	31,68	21,43	5476,5	0.504	5372,0
9	,08051	63853.	1932,9	512.8	3,769	3,144	33,04	20,47	8300,9	0.490	8173,8
RUN 69											
1	,00342	49904.	1344.0	626.1	2.147	0,161	37.13	18,39	23,3	0.776	15.6
2	,01174	51640.	1387.8	619.4	2.240	0,498	37.21	18,32	217,9	0.762	192,9
3	,01862	53468,	1502.0	616.2	2.437	0,758	35.60	19,15	521,7	0.752	482,8
4	,02562	55296,	1632,1	613.1	2.662	1,016	33.88	20.13	959,9	0.741	907,3
5	,03483	57124,	1677,8	605.8	2.770	1,368	34.05	19.98	1847,9	0.726	1775,4
6	,04338	59044,	1774.6	600.2	2.957	1,692	33.27	20.42	2924,0	0.713	2833,4
7	,05106	60871.	1809.1	595.6	3.189	2,000	32.05	21,19	4166,7	0.701	4059,3
8	,05947	62791.	2055.6	591.3	3.477	2,308	30.55	22,23	5610,4	0.688	5486,8
9	,07134	65350.	2090.3	581.2	3.597	2,796	31.26	21,63	8777,9	0.670	8625,2

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 70												
	1	,01248	52133.	1143.9	222.1	5.150	0,544	45.57	14.87	22.0	0.060	19.8
	2	,04001	53493.	1138.4	215.7	5.277	1,628	46.99	14.37	230.5	0.057	223.4
	3	,06621	55533.	1213.7	210.8	5.758	2,636	45.75	14.75	633.4	0.054	621.8
	4	,09159	57573.	1346.0	206.9	6.506	3,576	42.77	15.80	1146.3	0.051	1131.1
	5	,11987	59387.	1415.4	201.4	7.029	4,716	41.96	16.10	2007.6	0.048	1988.1
	6	,14875	61200.	1496.6	195.9	7.641	5,925	40.89	16.50	3136.3	0.044	3112.7
	7	,17814	63013.	1597.1	190.4	8.388	7,197	39.46	17.10	4502.3	0.041	4475.0
	8	,20762	64600.	1725.8	185.2	9.317	8,482	37.43	18.05	5945.3	0.039	5915.0
	9	,23954	65960.	1757.0	178.7	9.834	10,125	37.54	17.96	8297.2	0.035	8262.9
RUN 71												
	1	,01163	54690.	1248.4	250.4	4.987	0,508	43.81	15.48	25.4	0.081	22.6
	2	,03574	56063.	1269.8	244.5	5.193	1,444	44.15	15.33	233.7	0.077	225.3
	3	,05870	57435.	1341.2	240.0	5.589	2,303	42.82	15.81	616.6	0.073	603.2
	4	,08222	58808.	1416.7	235.3	6.021	3,185	41.51	16.31	1193.2	0.070	1175.1
	5	,10747	60410.	1469.0	229.5	6.400	4,190	41.12	16.44	2102.6	0.066	2079.2
	6	,13241	61783.	1543.9	224.4	6.881	5,188	40.02	16.90	3187.8	0.062	3159.7
	7	,15816	63385.	1628.4	218.9	7.439	6,268	38.92	17.36	4580.7	0.058	4548.0
	8	,18392	64758.	1732.4	213.7	8.105	7,357	37.38	18.09	6093.6	0.055	6057.1
	9	,21183	66268.	1769.8	207.2	8.543	8,724	37.44	18.03	8494.2	0.051	8452.6
RUN 72												
	1	,00728	54270.	1225.3	334.9	3.659	0,332	44.29	15.31	21.9	0.167	18.2
	2	,02363	55282.	1251.1	329.9	3.793	0,978	44.19	15.33	208.4	0.161	197.0
	3	,03969	56570.	1307.9	325.4	4.019	1,585	43.25	15.66	577.2	0.156	558.4
	4	,05607	57949.	1373.3	320.9	4.280	2,198	42.20	16.05	1143.3	0.151	1117.2
	5	,07402	59559.	1415.5	315.0	4.493	2,902	42.08	16.07	2071.1	0.145	2036.6
	6	,09104	61399.	1458.6	309.9	4.836	3,592	40.97	16.49	3213.6	0.140	3171.3
	7	,10938	63009.	1588.4	305.0	5.208	4,289	39.67	17.03	4571.6	0.134	4522.2
	8	,12699	64710.	1717.7	300.6	5.714	4,968	37.67	17.95	6018.0	0.129	5962.4
	9	,14723	66688.	1771.3	293.8	6.029	5,883	37.65	17.92	8598.3	0.123	8533.4

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Frg_i
RUN 73											
1	,00611	56983.	1429.3	424.3	3.369	0,277	39.87	17.08	25,9	0.297	20.6
2	,01902	57702.	1426.7	418.3	3.410	0,809	40.44	16,80	238,1	0.289	221.8
3	,03339	58899.	1447.5	412.3	3.511	1,336	40.69	16,67	699,2	0.280	671.5
4	,04608	60335.	1530.2	408.0	3.750	1,805	39.43	17,21	1313,1	0.273	1275.5
5	,06042	62011.	1579.0	401.8	3.929	2,360	39.27	17,24	2343,5	0.265	2293.9
6	,07447	63687.	1655.7	396.4	4.177	2,903	38.47	17,59	3622,1	0.257	3561.4
7	,08712	65363.	1820.8	393.3	4.630	3,350	35.90	18,88	4734,7	0.250	4666.1
8	,10091	67231.	1982.2	389.0	5.096	3,862	33,92	20.00	6241,8	0.243	6164.2
9	,11769	69194.	2004.8	380.9	5.263	4,602	34,51	19,59	9209,5	0.233	9117.1
RUN 74											
1	,00565	54419.	1890.5	449.4	2.872	0,234	42.17	16,14	21,5	0.344	16.4
2	,01692	56040.	1345.2	444.1	3.029	0,705	41.66	16,32	205,6	0.335	189.4
3	,02952	57892.	1400.8	438.2	3.197	1,189	41.33	16,42	629,8	0.326	601.4
4	,04113	59560.	1454.2	434.1	3.442	1,619	39.86	17,03	1202,7	0.319	1163.9
5	,05319	61366.	1599.5	429.8	3.722	2,064	38.36	17,69	1994,9	0.311	1945.4
6	,06624	63033.	1675.5	424.3	3.949	2,560	37.62	18,02	3149,0	0.302	3087.7
7	,07940	64839.	1774.9	419.1	4.235	3,064	36.53	18,55	4577,8	0.293	4504.8
8	,09251	66692.	1906.2	414.3	4.601	3,561	34.99	19,37	6199,3	0.285	6115.5
9	,10811	68405.	1913.9	406.2	4.711	4,243	35.74	18,90	9171,0	0.275	9070.9
RUN 75											
1	,01084	52083.	1126.9	244.9	4.602	0,476	46.22	14,68	20,9	0.076	18.4
2	,03422	53816.	1172.0	239.6	4.892	1,381	45.92	14,75	198,8	0.073	191.3
3	,05738	55549.	1243.3	234.8	5.294	2,251	44.68	15.15	553,7	0.069	541.4
4	,08136	57237.	1312.6	229.9	5.710	3,162	43.61	15,52	1117,8	0.066	1100.8
5	,10669	58970.	1367.3	224.2	6.098	4,174	43.13	15,67	1983,8	0.062	1961.7
6	,13167	60749.	1463.4	219.3	6.673	5,167	41.51	16,28	2996,7	0.059	2970.3
7	,15742	62482.	1563.8	214.2	7.302	6,228	39,96	16,92	4256,2	0.055	4225.6
8	,18355	64215.	1689.1	209.1	8.078	7,324	38.02	17,80	5671,2	0.052	5636.9
9	,21213	65902.	1733.6	202.5	8.562	8,724	38,02	17,76	7982,7	0.048	7943.4

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_{bi}/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 76											
1	,01322	54166.	1212.2	219.1	5.531	0,571	44.68	15.18	23.3	0.058	21.0
2	,04065	54857.	1211.6	213.6	5.672	1,625	45.28	14.95	214.0	0.055	207.3
3	,06800	56240.	1256.7	208.4	6.030	2,664	44.75	15.11	604.3	0.052	593.2
4	,00594	57623.	1303.8	203.1	6.420	3,751	44.20	15,29	1222,1	0.048	1206.8
5	,12471	59098.	1352.0	197.5	6.845	4,923	43.71	15,44	2116,4	0.045	2096.9
6	,15353	60481.	1417.6	192.3	7.373	6,122	42.66	15.82	3212.3	0.042	3188.9
7	,18287	62003.	1501.3	187.0	8.030	7,389	41.30	16.35	4532.3	0.040	4505.6
8	,21224	63616.	1028.7	182.0	8.949	8,661	39.06	17.31	5891,7	0.037	5862.3
9	,24428	65368.	1685.5	175.5	9.603	10,314	38,78	17.40	8160.0	0.034	8126.8
RUN 77											
1	,01843	54144.	1167.3	164.0	7.117	0,785	46.39	14.58	23,1	0.028	21.5
2	,05664	54557.	1158.1	158.6	7.310	2,255	47.11	14.34	216,3	0.026	211.6
3	,09424	55199.	1183.1	153.3	7.716	3,701	46.66	14.47	594,8	0.024	587.2
4	,13228	56209.	1226.1	148.2	8.275	5,220	45.84	14.73	1167,5	0.022	1157.4
5	,17176	57356.	1257.2	142.5	8.824	6,931	45.62	14.79	2019,2	0.020	2006.4
6	,21149	58870.	1324.6	137.0	9.671	8,742	44.44	15.18	3064,5	0.018	3049.5
7	,25238	60568.	1403.5	131.8	10.696	10,763	43.16	15.63	4377.8	0.016	4360.9
8	,29377	62633.	1540.6	125.6	12.263	12,894	40.65	16.61	5746,5	0.015	5728.2
9	,33824	65248.	1652.6	119.0	13.893	15,665	39.48	17,08	7916.8	0.013	7896.6
RUN 78											
1	,01482	52320.	1091.3	191.6	5.695	0,644	47,94	14.11	22,4	0.042	20.5
2	,04627	53941.	1122.1	186.0	6.032	1,871	48.07	14.04	217,3	0.039	211.5
3	,07780	55422.	1166.0	180.8	6.450	3,097	47.53	14.18	623,2	0.037	613.7
4	,10949	56997.	1232.0	175.8	7.009	4,348	46.26	14.57	1229,2	0.034	1216.3
5	,14263	58802.	1298.2	170.3	7.623	5,735	45.30	14.87	2122,5	0.032	2106.2
6	,17664	60654.	1373.6	164.7	8.339	7,236	44.16	15.25	3300,0	0.029	3280.4
7	,21151	62414.	1454.2	159.0	9.145	8,866	42.92	15.68	4767,1	0.027	4744.5
8	,24609	63895.	1575.6	153.9	10.240	10,466	40.55	16.62	6162,9	0.024	6138.4
9	,28333	65470.	1629.3	147.4	11.054	12,546	40.18	16.75	8473,9	0.022	8446.6

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 79												
	1	,01159	53971.	1195.5	244.1	4.898	0,508	45.15	15.01	24.1	0.076	21.4
	2	,03617	55260.	1210.6	238.2	5.082	1,467	45,65	14,81	229.1	0.072	221.1
	3	,06034	56642.	1254.8	233.1	5.384	2,392	45.14	14.97	643.1	0.068	629.9
	4	,08449	58023.	1316.5	228.2	5.769	3,317	44,07	15,33	1256,2	0.065	1238.2
	5	,10977	59635.	1377.1	222.6	6.180	4,327	43,31	15,59	2158,2	0.061	2135,3
	6	,13536	61155.	1446.5	217.6	6.648	5,375	42.28	15,96	3302,8	0.058	3275.2
	7	,16138	62628.	1525.3	212.3	7.184	6,472	41,06	16,43	4686,8	0.054	4654,9
	8	,18738	64470.	1662.5	207.4	8.014	7,565	38,78	17,42	6131,7	0.051	6096,4
	9	,21609	66312.	1717.4	200.8	8.551	8,995	38,61	17,46	8591,5	0.048	8551,1
RUN 80												
	1	,01583	54649.	1234.4	189.1	6.527	0,674	44,27	15,31	23,1	0.040	21.2
	2	,04871	55116.	1221.8	183.5	6.659	1,932	45.11	15.00	215,5	0.037	209,9
	3	,08128	56190.	1257.0	178.2	7.053	3,173	44,70	15,13	603,7	0.035	594,6
	4	,11424	57685.	1321.2	173.0	7.637	4,463	43.66	15,48	1195,1	0.032	1182,7
	5	,14832	59086.	1375,4	167.5	8.213	5,871	42.96	15,73	2043,5	0.030	2027.9
	6	,18279	60487.	1445.3	162.0	8.922	7,357	41,85	16,14	3103,7	0.028	3085.2
	7	,21818	61935.	1521.1	156.3	9.729	8,980	40.72	16,59	4424,5	0.025	4403,4
	8	,25355	63336.	1631.4	150.9	10.808	10,651	38.82	17,42	5809,0	0.023	5785,9
	9	,29139	64924.	1683.4	144.6	11.659	12,772	38,57	17,51	7985,5	0.021	7959,8
RUN 81												
	1	,01202	53944.	1209.4	236.3	5.117	0,523	44.60	15,21	23,4	0.070	20,9
	2	,03757	55339.	1229.7	230.5	5.335	1,513	45.00	15,04	223,2	0.066	215,5
	3	,06276	56966.	1288.0	225.3	5.716	2,472	44.23	15,29	626,9	0.063	614.4
	4	,08842	58408.	1344.5	220.2	6.106	3,462	43.44	15,55	1255,0	0.059	1237,9
	5	,11490	59850.	1397.3	214.7	6.508	4,524	42,83	15,76	2158,8	0.056	2136,9
	6	,14116	61384.	1487.6	209.8	7.092	5,578	41.26	16,37	3213,3	0.053	3187.4
	7	,16816	62593.	1560.5	204.6	7.629	6,712	40.11	16,84	4528,1	0.049	4498.2
	8	,19544	63942.	1661.2	199.4	8.329	7,882	38.49	17,57	5992,8	0.046	5959,6
	9	,22512	65709.	1708.9	192.8	8.863	9.381	38.45	17.55	8393,0	0.043	8355,1

RUN 82

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
1	,01034	48965.	1070.9	217.3	4.929	0,470	45.72	14,76	16,3	0.058	14.4
2	,03371	49604.	1106.0	213.3	5.184	1,386	44.85	15,06	157,2	0.055	151.4
3	,05791	50455.	1141.0	209.0	5.459	2,308	44.22	15,27	457,3	0.052	447.6
4	,08239	51520.	1190.6	204.7	5.816	3,243	43.27	15,61	916,4	0.050	903,0
5	,10796	52712.	1233.1	199.9	6.168	4,260	42.75	15,79	1594,2	0.047	1577.0
6	,13374	54075.	1296.9	195.3	6.642	5,306	41.69	16,18	2445,9	0.044	2425,1
7	,16008	55565.	1375,9	190.5	7.221	6,408	40.38	16,71	3485,3	0.042	3461.3
8	,18668	57055.	1479.0	186.0	7.952	7,534	38,58	17,51	4627,5	0.039	4600,7
9	,21592	58545.	1505.5	179.9	8.369	9,002	38,89	17,33	6564,2	0.036	6533,5

RUN 83

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
1	,01052	47568.	924,5	199.6	4.632	0,490	51.45	13.06	15,5	0.047	13.8
2	,03377	48522.	999.7	196.9	5.076	1,402	48,54	13,89	135,7	0.045	130.7
3	,05861	49517.	1058,9	193.3	5.477	2,344	46.76	14,44	389,8	0.043	381,6
4	,08540	50595.	1101.8	188.9	5.832	3,365	45,92	14,70	817,1	0.041	805.7
5	,11309	51840.	1141,5	184,1	6,201	4,474	45.41	14,86	1454,9	0.038	1440,0
6	,14112	53333.	1202.9	179.4	6.706	5,629	44.34	15,21	2272,3	0.036	2254,3
7	,16978	55033.	1284,6	174.6	7.357	6,846	42.84	15,75	3269,0	0.033	3248,1
8	,19862	56816.	1404.1	170.1	8.252	8,071	40.46	16,69	4312,6	0.031	4289.4
9	,23050	58475.	1442,5	164.1	8.790	9,699	40.54	16,63	6134,4	0.029	6107,8

RUN 84

i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
1	,01553	52758.	1161.6	187.1	6.207	0,661	45.42	14,93	21,5	0.039	19.7
2	,04780	53238.	1150,5	181.6	6,334	1,895	46,27	14,63	200,5	0.036	195.1
3	,07965	54197.	1180.3	176.6	6.685	3,105	45,92	14,73	559,0	0.034	550.3
4	,11151	55252.	1229,4	171.7	7.160	4,334	44,94	15,05	1085,7	0.032	1074.0
5	,14469	56835.	1289.3	166.4	7.749	5,692	44,08	15,34	1852,6	0.029	1837,8
6	,17858	58609.	1369.3	161.0	8.505	7,144	42,80	15,79	2835,1	0.027	2817,6
7	,21333	60672.	1480,5	155.6	9.516	8,707	40.98	16,50	4021,7	0.025	4001,7
8	,24869	62590.	1618.9	150.2	10.775	10,351	38.66	17,51	5312,1	0.023	5290,2
9	,28694	64749.	1700.1	143.6	11.835	12,475	38,09	17,74	7399,5	0.020	7374,9

	i	X_{bi}	q_i	h_{TPi}	h_{Li}	h_{TPi}/h_{Li}	$(1/X_{tt})_i$	ΔT_{fi}	$(T_b/\Delta T_f)_i$	Fr_i	Fr_{Li}	Fr_{gi}
RUN 65												
	1	,01655	52555.	1135.4	176.2	6.445	0,705	46,29	14,63	21,5	0.034	19.8
	2	,05104	53766.	1159.6	170.7	6.792	2,025	46,37	14,59	201,3	0.031	196.3
	3	,08571	54977.	1198.4	165.5	7.241	3,354	45,87	14,73	572,1	0.029	564.0
	4	,12085	56285.	1249.8	160.3	7.797	4,744	45,03	15,00	1142,0	0.027	1130.9
	5	,15711	57641.	1297.7	154.8	8.383	6,267	44.42	15,20	1961,6	0.025	1947.7
	6	,19369	59094.	1369.1	149.4	9.162	7,870	43.16	15,64	2969,6	0.023	2953.3
	7	,23106	60548.	1450.4	143.9	10.077	9,607	41.74	16,18	4185,2	0.021	4166.6
	8	,26911	62485.	1582.6	138.4	11.431	11,466	39,48	17.12	5531,0	0.019	5510.8
	9	,30994	64423.	1649.5	131.8	12.513	13,860	39.06	17,28	7672,0	0.017	7649.5

5. Discussion

5.1. Basis for the correlation of the heat transfer coefficients

The object of this work is to investigate the effect of gravitational forces on heat transfer rates in natural circulation, vertical tube evaporators. Local heat transfer data in the two-phase convective region of this work are used to obtain a correlation of the heat transfer coefficients.

It is convenient to start by considering the variables involved in the process of evaporation in thermosiphon reboilers. The independent variables are the submergence S and the overall temperature difference ΔT_{ov}. The film temperature difference ΔT_f is often used instead of ΔT_{ov}. However, ΔT_f is not a truly independent variable in this type of system. ΔT_f and the heat flux q are closely related as shown in Figure 5.1. where curves of length-mean heat flux versus length-mean ΔT_f are shown. The interdependence between these quantities can be expressed as:

$$f(\bar{q}, \overline{\Delta T}_f, S) = 0 \tag{5.1}$$

The submergence determines the hydrostatic head available to sustain a flow. The mass flow rate, W will depend on the submergence, on the quality of the two-phase mixture and on the physical properties of both phases.

$$W = g\ (S, x, \text{physical properties}) \tag{5.2}$$

As submergence is not often used as an independent variable in heat transfer correlations, it is convenient to eliminate it by combining the relationships 5.1 and 5.2 to give:

$$F\ (\bar{q},\ \Delta\bar{T}_f,\ W,\ x,\ \text{physical properties}) = 0 \qquad (5.3)$$

Alternatively, the following dependences can be written:

$$F\ (\bar{q},\ \Delta\bar{T}_f,\ W_L,\ x,\ \text{physical properties}) = 0 \qquad (5.4)$$

and

$$F\ (\bar{q},\ \Delta\bar{T}_f,\ W_g,\ x,\ \text{physical properties}) = 0 \qquad (5.5)$$

These dependences are valid for the local and the length-mean heat transfer data. It is reasonable to assume that the two-phase heat transfer coefficients will depend on the quantities contained in equations 5.3 to 5.5.

Many authors correlate local heat transfer coefficients in the convective region by equations of the form:

$$\frac{h_{TP}}{h_L} = A\left(\frac{1}{X_{tt}}\right)^n \qquad (5.6)$$

The use of equations of this type has been justified, among others, by Collier (C1) who suggested that $1/X_{tt}$ is a natural parameter for an annular type of flow.

The Lockhart-Martinelli parameter was defined for horizontal annular flow in reference L2:

$$X = \sqrt{\left(\frac{\Delta P}{\Delta L}\right)_L \Big/ \left(\frac{\Delta P}{\Delta L}\right)_g} \tag{5.7}$$

where $(\Delta P/\Delta L)_L$ and $(\Delta P/\Delta L)_g$ are respectively the pressure drops for the liquid phase and for the gas phase assuming each phase to flow alone in the channel. When both phases flow turbulently, this parameter becomes:

$$X_{tt} = \left(\frac{W_L}{W_g}\right)^{0.9} \left(\frac{\rho_g}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_g}\right)^{0.1} \tag{5.8}$$

or it could be written as:

$$X_{tt} = \left(\frac{1-x}{x}\right)^{0.9} \left(\frac{\rho_g}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_g}\right)^{0.1} \tag{5.9}$$

The liquid phase heat transfer coefficient h_L was introduced to account for the effect of the mass flow rate on the two-phase heat transfer coefficient h_{TP} in boiling systems.

Correlations of this type have been applied to both forced and natural circulation heat transfer data, and they have not been entirely successful, as the constants reported by several investigators are quite different. It can be thought that the reason for this is that $1/X_{tt}$ alone is not a sufficient parameter. The Lockhart-Martinelli parameter was originally defined for the horizontal two-phase flow of two-component mixtures without heat transfer. Therefore, it does not account for the influence of gravity on flow patterns and heat transfer in vertical flow, nor does it account for the effect of nucleation.

Davis (D2) showed that a better correlation of pressure drop data in vertical flow can be obtained if the parameter X_{tt} used in the

Lockhart-Martinelli pressure drop correlation is modified by including a Froude number based on the average velocity of the two-phase mixture. Chawla (C7) emphasized that the influence of gravity should be accounted for in correlations of heat transfer coefficients and proposed one in terms of a Froude number based on the liquid superficial velocity.

In annular flow most of the heat is transferred to the two-phase mixture through the liquid film. The influence of gravity in annular flow is also exerted mainly on the liquid film. This force opposes the movement of liquid in vertical ascending flow and tends to thicken the film. The vapour core, moving faster than the liquid, tends to drag it upwards, producing a thinning of the film. Therefore the interaction of inertia and gravity forces will affect the thickness of the film, on which the thermal resistance of the liquid depends.

The Froude number is often used as a similarity parameter in liquid flows with a free surface whose shape and surface behaviour are affected by the interaction of gravity and inertia forces. It seems reasonable to think of the Froude number as a factor describing the combined effects of those forces on the flow and heat transfer mechanisms in annular flow. Froude number is significant as it accounts for the effect of the velocity of the mixture on the thickness of the liquid film.

When equations of the type of 5.6 are used, it is implicitly assumed that nucleation is completely suppressed. This assumption is not entirely justified in most of the data from evaporators, especially those of the natural circulation type. Guerrieri and Talty (G1) found that the convective and nucleate mechanisms coexisted along most of the length of their test sections and accordingly, they used only the heat transfer coefficients from the top of their test sections to obtain a correlation for the convective region. The success of Chen's correlation (C5) is due to the fact that the interaction of both mechanisms is taken into account over the entire quality range.

Curves of local h_{TP}/h_L versus $1/X_{tt}$ for four typical runs of this work are shown in Fig. 5.2. This shape of the curves is the same as reported by many authors (C1, B1, S1, P1, C6). At low values of $1/X_{tt}$, h_{TP}/h_L is independent of it, indicating that the main mechanism of heat transfer is nucleate boiling. When the convective mechanism becomes significant, h_{TP}/h_L increases with $1/X_{tt}$. Attempts by some authors (S1, P1) to correlate heat transfer coefficients by adding in one correlation the nucleate boiling contribution (dependent on the boiling number) and the convective one (dependent on $1/X_{tt}$) have proved unsuccessful. From the work of Chen (C5) it becomes apparent that a better correlation can be obtained if both mechanisms are considered to affect each other. From the results of that work it becomes clear that the value of heat transfer coefficient in any case will depend on the degree to which nucleation is suppressed by the effect of velocities, and the convective mechanism is enhanced by these velocities.

The present work is mostly concerned with heat transfer in the region where nucleation is not the dominant heat transfer mechanism.

Accordingly, attempts will be made to modify equations of the type of 5.6 by including the Froude number believing that it describes the effects of velocities and gravity on the liquid film, and consequently on the rates of heat transfer in a convection-dominated regime.

Three different forms of the Froude number (based on the homogeneous velocity of the two-phase mixture, on the superficial liquid velocity and on the superficial vapour velocity) have been defined in earlier chapters.

The homogeneous and vapour phase Froude numbers increase from bottom to top of the tube, reflecting the increase in the vapour flow rate due to evaporation. Conversely, the liquid Froude number decreases along the tube.

The relationship between h_{TP}/h_L and the Froude number cannot be found directly from a plot of local values of these quantities for any single run, because the variation of Fr along the tube is accompanied by a variation in $1/X_{tt}$. In order to study the effect of Froude number alone, local data points from different runs at a constant value of $1/X_{tt}$ are considered.

Fig. 5.3 shows a plot of the local heat transfer ratio h_{TP}/h_L versus $1/X_{tt}$ for three small ranges of the homogeneous Froude number Fr. The three groups of points shown have been taken from different runs, (see Table 5.1.) The points with approximately the same Fr tend to form a separate line. We can deduce from Fig. 5.3 that at a constant value of the Lockhart-Martinelli parameter, h_{TP}/h_L increases with a decrease in Fr. From the data in Tables 5.2 and 5.3 and Fig. 5.4 and 5.5. it can be seen that the liquid and vapour-phase Froude number indicate the same pattern of behaviour. This suggests that the heat transfer ratio h_{TP}/h_L does not depend solely on $1/X_{tt}$ but also on Froude number whether expressed in terms of the homogeneous velocity or the superficial velocity of either phase.

The importance of the wall superheat or film temperature difference in determining the operating conditions of thermosiphon reboilers has already been considered. Calus et al. (C6, M1) successfully correlated length-mean and local heat transfer coefficients by incorporating the dimensionless reciprocal of the film temperature difference, $T_b/\Delta T_f$ as a correlating parameter alongside $1/X_{tt}$.

The following form of correlation is therefore proposed for local heat transfer coefficients:

$$\frac{h_{TP}}{h_L} = A \left(\frac{1}{X_{tt}}\right)^{b_1} \left(\frac{T_b}{\Delta T_f}\right)^{b_2} \left(\frac{V^2}{gD}\right)^{b_3} \qquad (5.10)$$

where (V^2/gD) is the Froude number in terms of a velocity V which can be identified with any of the three forms considered.

5.2. Correlation of experimental local heat transfer coefficients

The experimental results described in the preceding chapter were used to develop correlations of the type of 5.10.

85 runs gave a total of 765 local data points. The first step in the correlating procedure was to identify the points in which the

Table 5.1

Data points shown in Fig. 5.3

-	Run Number	Compartment Number	$\frac{1}{X_{tt}}$	$\frac{h_{TP}}{h_L}$	Fr
Fr between 1000 and 1100	1	9	1.251	2.867	1066.0
	6	8	0.611	1.648	1089.0
	7	7	0.627	1.772	1091.7
	12	7	0.856	2.276	1037.9
	13	7	0.780	2.169	1068.1
	16	6	1.126	2.787	1084.7
	18	6	0.924	2.697	1082.7
	19	6	0.896	2.423	1010.7
	21	5	0.721	2.253	1031.5
	27	5	0.895	2.404	1091.9
	32	5	1.362	3.062	1096.9
	54	4	3.914	6.430	1029.1
	58	4	1.858	3.910	1037.4
	59	4	1.762	3.867	1002.1
	63	4	1.320	3.164	1010.8
	67	4	1.282	3.090	1074.0
	68	4	1.195	2.960	1037.1
	84	4	4.334	7.160	1085.7
Fr between 2200 and 2300	7	9	0.876	1.771	2301.5
	12	9	1.224	2.392	2302.0
	22	8	3.283	5.279	2302.8
	23	8	2.040	3.709	2279.0
	27	7	1.265	2.743	2283.0
	38	7	1.422	2.803	2245.9
	44	6	3.208	4.788	2205.0
	48	6	1.909	3.391	2221.7
	49	6	1.828	3.239	2206.6
	83	6	5.630	6.706	2272.3
Fr between 3400 and 3600	23	9	2.450	3.783	3461.9
	36	8	2.004	3.547	3505.9
	40	8	1.745	3.004	3598.4
	50	7	2.328	3.703	3459.2
	52	7	1.856	3.172	3464.5
	55	7	4.959	5.935	3584.8
	56	7	4.115	5.191	3575.6
	82	7	6.408	7.221	3485.3

Table 5.2

Data Points Shown in Fig. 5.4

—	Run Number	Compartment Number	$\frac{1}{X_{tt}}$	$\frac{h_{TP}}{h_L}$	Fr_L
Fr_L between 0.050 and 0.055	70	4	3.576	6.506	0.051
	71	9	8.724	8.543	0.051
	75	7	6.228	7.302	0.055
	75	8	7.324	8.078	0.052
	76	3	2.664	6.030	0.052
	79	8	7.565	8.014	0.051
	79	7	6.472	7.184	0.054
	81	6	5.578	7.092	0.053
	82	4	3.243	5.816	0.050
	82	3	2.308	5.459	0.052
Fr_L between 0.100 and 0.120	22	9	3.897	5.482	0.119
	28	3	1.460	4.303	0.109
	28	4	2.005	4.481	0.105
	28	5	2.599	4.642	0.102
	43	4	2.062	4.430	0.120
	43	5	2.683	4.620	0.116
	43	6	3.313	4.868	0.112
	43	7	3.931	5.211	0.108
	43	8	4.538	5.676	0.104
	43	9	5.350	5.912	0.100
	44	8	4.402	5.698	0.118
	44	9	5.211	6.058	0.113
	56	7	4.115	5.191	0.116
	56	8	4.786	5.628	0.111
	56	9	5.696	5.925	0.106
Fr_L between 0.58 and 0.60	16	9	1.809	3.256	0.594
	24	5	0.977	2.787	0.599
	24	6	1.215	2.898	0.591
	24	7	1.431	3.136	0.584
	36	6	1.486	3.093	0.597
	36	7	1.746	3.298	0.588
	36	8	2.004	3.547	0.580
	51	7	1.949	3.414	0.590
	51	8	2.263	3.603	0.579

Table 5.3

Data Points in Fig. 5.5

	Run Number	Compartment Number	$\frac{1}{X_{tt}}$	$\frac{h_{TP}}{h_L}$	Fr_g
Fr_g between 1000 and 1100	1	9	1.251	2.867	1022.6
	10	7	1.100	2.483	1096.1
	16	6	1.126	2.787	1043.3
	17	6	1.099	2.561	1087.0
	18	6	0.924	2.697	1019.3
	27	5	0.895	2.404	1025.2
	31	5	1.777	3.609	1103.9
	32	5	1.362	3.062	1054.7
	54	4	3.914	6.430	1016.8
	58	4	1.858	3.910	1008.8
	67	4	1.282	3.090	1028.5
	75	4	3.162	5.710	1100.8
	84	4	4.334	7.160	1074.0
Fr_g between 2200 and 2300	10	9	1.509	2.798	2238.8
	12	9	1.224	2.392	2206.3
	22	8	3.283	5.279	2269.3
	23	8	2.040	3.709	2222.5
	47	6	2.432	3.919	2298.0
	51	6	1.648	3.192	2276.4
	73	5	2.360	3.929	2293.9
	83	6	5.629	6.706	2254.3
Fr_g between 3400 and 3600	23	9	2.450	3.783	3393.0
	33	8	2.202	3.691	3593.7
	36	8	2.004	3.547	3416.3
	40	8	2.122	2.965	3491.4
	53	7	1.823	3.240	3507.7
	55	7	4.959	5.935	3551.8
	56	7	4.115	5.191	3535.0
	64	7	2.320	3.610	3573.8
	73	6	2.903	4.177	3561.4
	82	7	6.408	7.221	3461.3

nucleate mechanism dominated over the convective one. It is assumed (A1, B1) that nucleation mechanism prevails at qualities below 2%, although it can still be found to be the dominant process above this limit, particularly at high heat fluxes.

500 out of the 765 experimental local data points of this work have qualities of 2% or more, and liquid and vapour Reynolds numbers above 2000. On the basis of these data points, the local heat transfer ratio h_{TP}/h_L was correlated with $1/X_{tt}$, giving the equation:

$$\frac{h_{TP}}{h_L} = 2.66 \left(\frac{1}{X_{tt}}\right)^{0.54} \tag{5.11}$$

The numerical constants of this equation were obtained by means of a linear regression routine. Equation 5.11 correlates most of the data points with an accuracy of ±30%.

Fig. 5.2 shows the line of equation 5.11 in log-log co-ordinates, together with all the local points of runs 48, 72, 83 and 85 which had qualities above 2%. The points showing bigger deviations (up to +75%) from the correlating line are those obtained in the lower compartments of the evaporator tube, at low quality and low $1/X_{tt}$. These conditions correspond to a dominance of the nucleate boiling mechanism.

In Section 3.4 the errors in the experimental heat transfer coefficients were found not be be higher than ±30%. The maximum deviation of experimental local heat transfer ratios h_{TP}/h_L from the correlating line 5.11 should not greatly exceed this maximum. It has been decided arbitrarily to exclude only the points that exceeded a deviation of ±40% from the correlation procedure. This restriction resulted in the elimination of data points from the two bottom compartments of the evaporator tube.

The remaining 473 data points were again correlated by an equation of the type of 5.8, giving the following correlation:

$$\frac{h_{TP}}{h_L} = 2.54 \left(\frac{1}{X_{tt}}\right)^{0.566} \tag{5.12}$$

with an accuracy indicated in Table 5.4 and Fig. 5.6.

Table 5.4.

Accuracy of Local Correlations

Equation number	Maximum error limits, %	Accuracy limit for N% of the data points	Percentage of data points within the accuracy limits, N	Sum of squares of deviation between experimental and predicted h_{TP}/h_L
5.12	+38.70 -31.99	±30%	95.8%	156.402
5.13	+18.84 -29.78	±15%	97.88%	29.058
5.14	+19.75 -30.35	±15%	97.67%	31.046
5.15	+18.81 -29.89	±15%	98.09%	28.466

In order to obtain correlations of the type of 5.10 three forms of the Froude number are considered:

Fr, based on the homogeneous fluid velocity,

Fr_L, based on the superficial velocity of the liquid phase,

Fr_g, based on the superficial velocity of the vapour phase.

The method of multivariable linear regression was chosen to obtain the numerical constants in correlations of the type of 5.10. This method, as described by Volk (V1) minimises the sum of squares of deviations of experimental from predicted values of the dependent variable. It was used by Wright and co-workers (W2) to correlate heat transfer coefficients in the convective region.

The application of the linear regression routine is shown in Appendix IV. The following expressions are arrived at:

$$\frac{h_{TP}}{h_L} = 8.011 \left(\frac{1}{X_{tt}}\right)^{0.735} \left(\frac{T_b}{\Delta T_f}\right)^{0.062} Fr^{-0.194} \qquad (5.13)$$

$$\frac{h_{TP}}{h_L} = 2.146 \left(\frac{1}{X_{tt}}\right)^{0.307} \left(\frac{T_b}{\Delta T_f}\right)^{0.0385} Fr_L^{-0.187} \qquad (5.14)$$

$$\frac{h_{TP}}{h_L} = 7.957 \left(\frac{1}{X_{tt}}\right)^{0.738} \left(\frac{T_b}{\Delta T_f}\right)^{0.06} Fr_g^{-0.194} \qquad (5.15)$$

The correlating accuracy of these equations can be found in Table 5.4. The correlations developed here for the heat transfer coefficients of this work are a significant improvement on equation 5.12. Figs. 5.7, 5.8 and 5.9 show the degree of agreement between the experimental results and the predictions of equations 5.13, 5.14 and 5.15. respectively. The correlating properties of equation 5.15. are slightly better than those of the other two, as it may be seen from Table.5.4.

The method of linear regression was expected to assign the best values to the exponents of the different parameters to fit the present data. $1/X_{tt}$ has a different exponent in each of the equations 5.13 to 5.15. The reason for this is that Fr, Fr_L and Fr_g are related with $1/X_{tt}$ by their dependence on the mass flow rates W_L and W_g.

In equation 5.14:

$$h_{TP} \propto \left(\frac{1}{X_{tt}}\right)^{0.307} Fr_L^{-0.187}\ h_L$$

But

$$\frac{1}{X_{tt}} \propto \left(\frac{W_g}{W_L}\right)^{0.9}$$

$$Fr_L \propto W_L^{\,2}$$

$$h_L \propto W_L^{\,0.8}$$

Therefore

$$h_{TP} \propto \left(\frac{W_g}{W_L}\right)^{0.9(0.307)} W_L^{\,2(-0.187)}\ W_L^{\,0.8}$$

$$h_{TP} \propto W_g^{\,0.276}\ W_L^{\,0.15} \qquad (5.14A)$$

In equation 5.15:

$$h_{TP} \propto \left(\frac{1}{X_{tt}}\right)^{0.738} Fr_g^{-0.194}\ h_L$$

But $Fr_g \propto W_g^{\ 2}$

Therefore

$$h_{TP} \propto \left(\frac{W_g}{W_L}\right)^{0.9(0.738)} W_g^{\ 2(-0.194)} \ W_L^{\ 0.8}$$

$$h_{tp} \propto W_g^{\ 0.276} \ W_L^{\ 0.136} \qquad (5.15A)$$

It can be seen from equations 5.14A and 5.15A, that equations 5.14 and 5.15, predict approximately the same dependence for the two-phase heat transfer coefficients on the liquid and vapour flow rates. Therefore, these two equations can be considered as equivalent.

The exponents of $1/X_{tt}$ and $T_b/\Delta T_f$ in equations 5.13. and 5.15 are very similar. This is because the homogeneous and vapour phase Froude numbers differ very little numerically.

5.3. Correlation of length-mean heat transfer coefficients

The experimental length-mean heat transfer coefficients from runs in which the length-mean quality was 2% or more were compared with the predictions of equations 5.12, 5.13, 5.14 and 5.15. The accuracy of each of these equations in correlating the length-mean data may be found in Table 5.5 and Figs. 5.10, 5.11, 5.12 and 5.13. It is concluded that the length-mean coefficients of this work are well correlated by equations developed from local heat transfer data and that correlations including the Froude number and the reciprocal of the film temperature difference are an improvement on equation 5.12

The length-mean coefficients were also correlated by means of the following equation:

$$\frac{h_{TP}}{h_L} = 0.0415 \left(\frac{1}{X_{tt}}\right)^{0.822} \left(\frac{T_b}{\Delta T_f}\right)^{0.575} Fr^{-0.0094} \qquad (5.16)$$

The linear regression routine already mentioned was used. It correlated 97% of the length-mean data points to within ±4%. In developing the correlation 5.16 only the data points with the length-mean average quality higher than 2% were used. It is interesting to note that this length-mean correlation does not correlate the local data points. Fig. 5.14 shows the local data points from runs 48 and 83.

The local data points from the two bottom compartments (1 and 2), where the predominant mechanism of heat transfer was nucleation are not shown in this plot. It can be seen that the heat transfer ratios h_{TP}/h_L from the lower compartments 3 and 4 are underestimated by equation 5.16, while those from compartments 6, 7, 8 and 9 are overestimated. Only the heat transfer coefficients in the middle compartment are always correlated within the ±15% accuracy limits. The range of the homogeneous Froude numbers in this zone is approximately equal to that of the homogeneous length-mean Froude number as indicated in Table 5.6.

The large axial variation in the magnitude of the homogeneous Froude number in any run is probably not accounted for by its exponent in equation 5.16. As a result, this equation predicts heat transfer ratios h_{TP}/h_L higher than the experimental ones in the upper half of the tube.

Table 5.5

Comparison of Length-mean Data Points with Local Correlations

Equation number	Maximum error limits, %	Accuracy limit for N% of the data points	Percentage of data points within the accuracy limits, N	Sum of squares of deviation between experimental and predicted h_{TP}/h_L
5.12	+23.66 -24.20	±20%	94%	15.114
5.13	+13.09 -29.09	±15%	97.64%	2.443
5.14	+13.73 -29.72	±15%	97.64%	2.655
5.15	+12.57 -29.31	±15%	97.64%	2.442

Table 5.6

Ranges of the Homogeneous Froude Number

Length-mean	Local, in the middle compartment	Local, in all individual compartments
245.8-2294.0	238.8-2343.5	1.7-9209.5

5.4. Comparison of the present data with some published correlations

A comparison of both local and length-mean data of this work with the predictions of earlier heat transfer correlations is made in this section. Three correlations originally obtained from water data are used for this purpose. The experimental conditions that served to arrive at these correlations are summarized in Table 5.7, together with those of the present work.

5.4.1. The Dengler-Addoms correlation (D3)

Dengler and Addoms correlated local heat transfer coefficients in forced vertical upflow by the expression:

$$\frac{h_{TP}}{h_L} = 3.5 \left(\frac{1}{X_{tt}}\right)^{0.5} \qquad (5.17)$$

85% of their local data points in which nucleation was believed to be suppressed were correlated to within ±20% by equation 5.17, which applied in the range of $1/X_{tt}$ from 0.25 to 70. Fig. 5.15 shows the line of equation 5.17 and the data points used in this work. Most of the data is below the correlating line, with 36.6% of the data within the ±20% accuracy lines. 94.5% of the points are between the correlating line and the -35% accuracy line.

5.4.2. The Schrock-Grossman correlation (S1)

On the basis of the experiments with water in the range of variables specified in Table 5.7, Schrock and Grossman proposed the equation:

$$\frac{Nu}{Re\ Pr^{1/3}} = 170 \left[Bo + 1.5 \times 10^{-4}\ X_{tt}^{-2/3} \right]$$

which is more frequently written as:

$$\frac{h_{TP}}{h_L} = 0.739 \left[Bo \times 10^4 + 1.5 \left(\frac{1}{X_{tt}}\right)^{2/3} \right] \qquad (5.18)$$

This equation correlated their local data to within ±35%. Fig. 5.16 shows the local heat transfer coefficients of the present work plotted as h_{TP}/h_L versus $Bo \times 10^4 + 1.5(1/X_{tt})^{2/3}$. The line of equation 5.18 is also indicated. It can be seen that 95% of the present local data points are well within the ±35% accuracy lines.

5.4.3. <u>The correlation of Abid (A1)</u>

From experiments conducted in natural circulation reboilers, Abid obtained the equation:

$$\frac{h_{TP}}{h_L} = 0.043\ Ga^{0.21} \left(\frac{1}{X_{tt}}\right)^{0.7} \left(\frac{\ell}{Z}\right)^{0.21} . \qquad (5.19)$$

where Ga is the Galileo number, ℓ is half the length of the tube and Z is the distance from the tube inlet to the centre of each compartment. Equation 5.19 correlated 85% of his local water data points to within ±30%.

The comparison of this equation with the present local data is shown in Fig. 5.17. The data of this work are below the correlating line. 37.4% of the data points are within the recommended accuracy limits of ±30%.

Despite the restricted range of variables in this work the agreement of this data with equations 5.17, 5.18 and 5.19. is relatively good.

Table 5.7

Summary of experimental details of correlations 5.17., 5.18. and 5.19 and this work

Investigator and Equation	Tube Diameter	Heating Medium	Flow System	Heat flux BTU/hr ft^2	Exit quality %	Mass flux lb/hr ft^2
Dengler and Addoms 5.17	1 in.	Steam	Forced Upflow	30000-156000	0-100	4.4×10^4 101×10^4
Schrock and Grossman 5.18	0.1181 in. 0.2370 in. 0.4317 in.	Electric	Forced Upflow	60000-145000	5-57	1.76×10^4- 328×10^4
Abid 5.19	0.872 in. 0.5 in.	Steam	Natural Circulation	10176-116500	1.2-64.5	2.9×10^4- 54.9×10^4
Present work	0.872 in.	Steam	Natural Circulation	15220-69200	1.97-36.2	5.6×10^4 50.2×10^4

5.5. Comparison of the proposed correlation with the data of other workers

The correlation of local heat transfer coefficients in terms of the homogeneous Froude number, equation 5.13, was compared with data obtained by B.A. Abid on the same apparatus. 310 local data points from 63 runs with water were used for the comparison. These points had qualities above 2%, and the liquid and vapour Reynolds numbers above 2000.

The line of equation 5.13 is shown in Fig. 5.18, together with Abid's data points. It can be seen that most of the data points are above the line. The deviation of the data ranges from 0 to about +100%, with 46% of the points between the line of equation 5.13 and the +35% accuracy line. This discrepancy may be due to the fact that equation 5.13 was obtained from data covering a restricted range of quality and heat flux, as shown in Table 5.8. The points which are closer to the line of equation 5.13 are those corresponding to low values of the parameter:

$$\left(\frac{1}{X_{tt}}\right)^{0.735} \left(\frac{T_b}{\Delta T_f}\right)^{0.062} Fr^{-0.194}$$

for which the quality and the heat flux are low.

Table 5.8

-	Local Qualities	Local Heat Flux, BTU/hr ft²
Abid's data	2.0-60.2	10176-116500
Present data	2.0-33.8	15220-69200

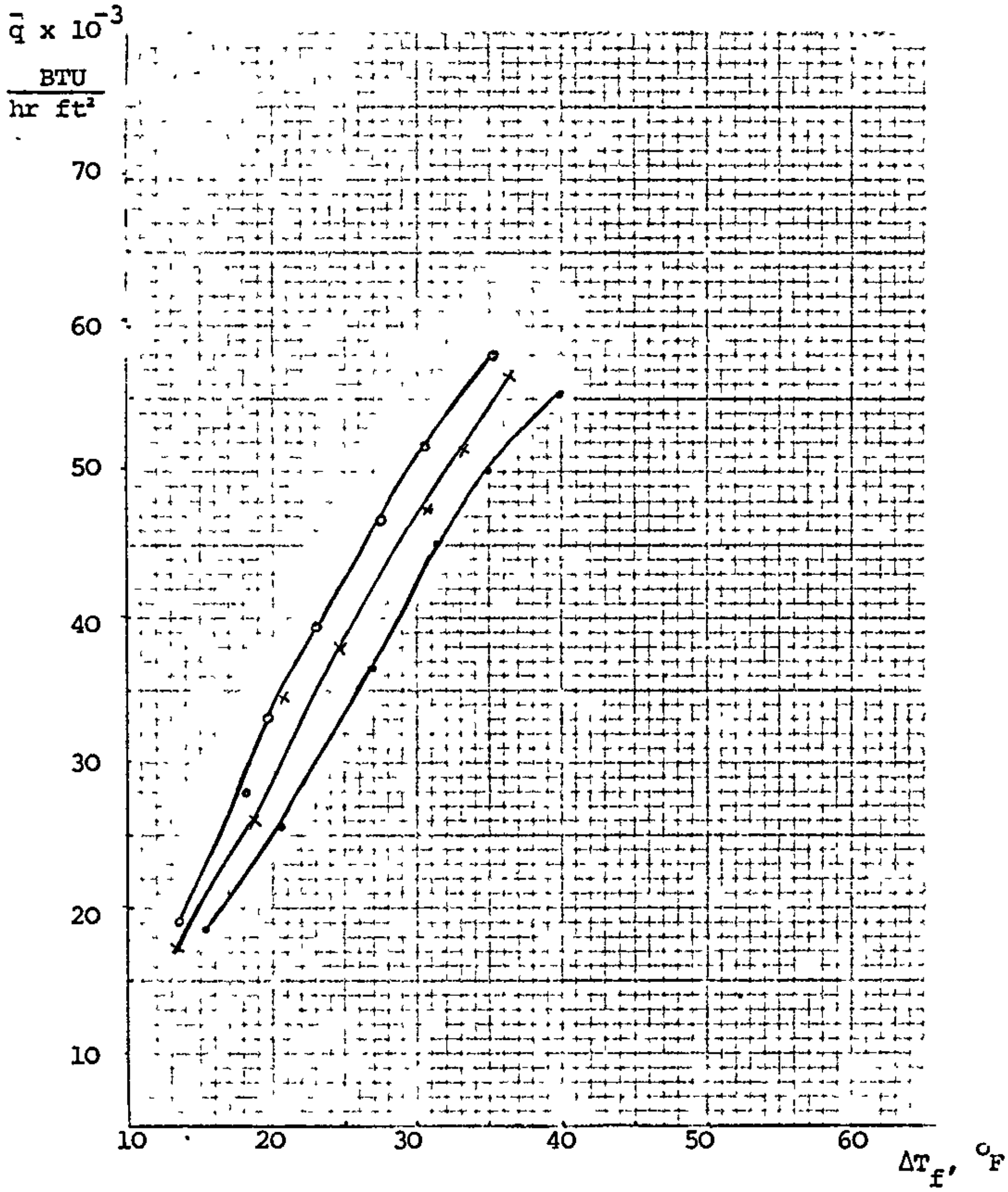

Fig. 5.1. Length-mean heat flux versus film temperature difference for different submergences.

• S = 50%
x S = 70%
o S = 90%

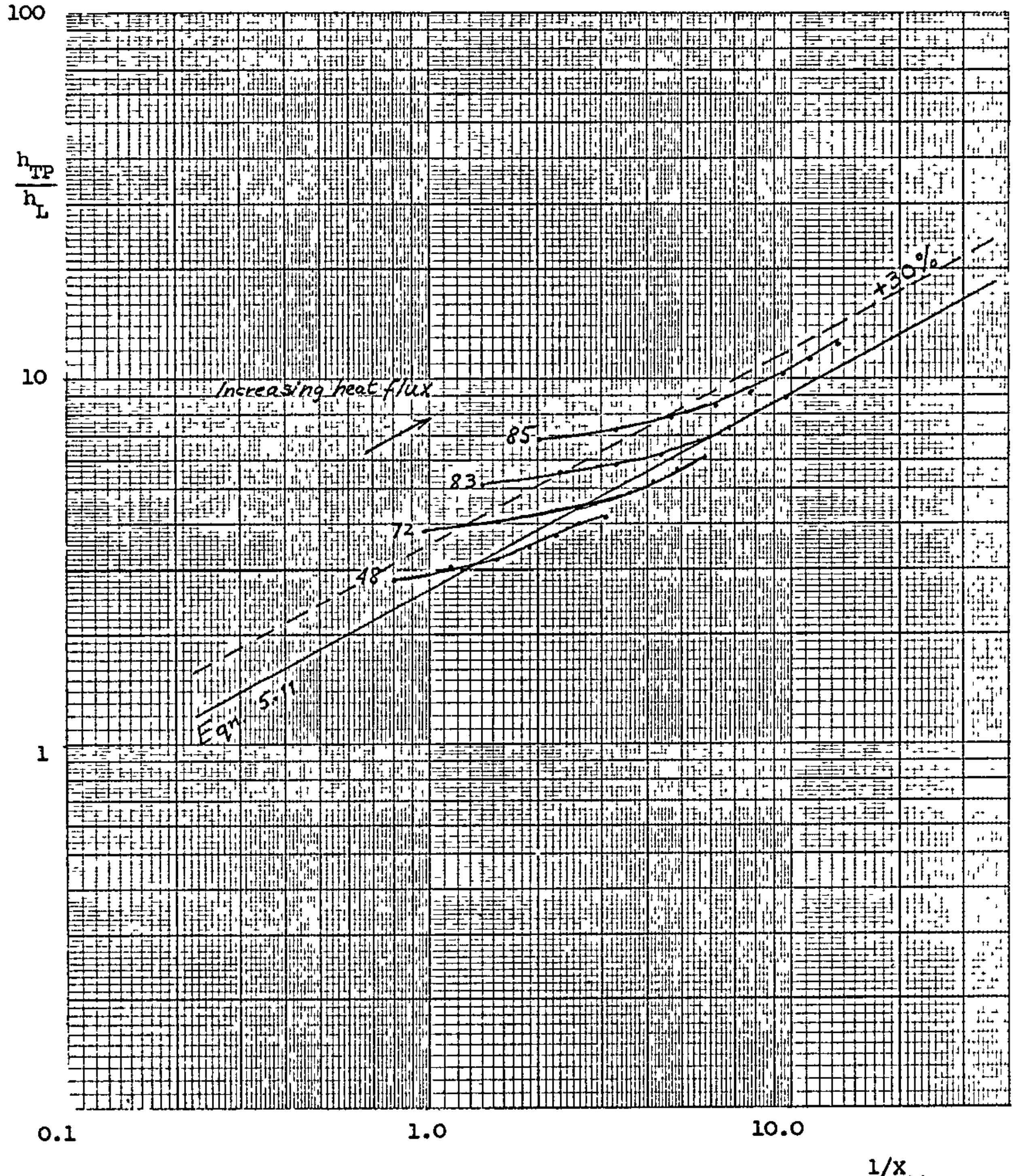

Fig. 5.2. Local heat transfer coefficient ratio h_{TP}/h_L versus $1/X_{tt}$ for four typical runs.

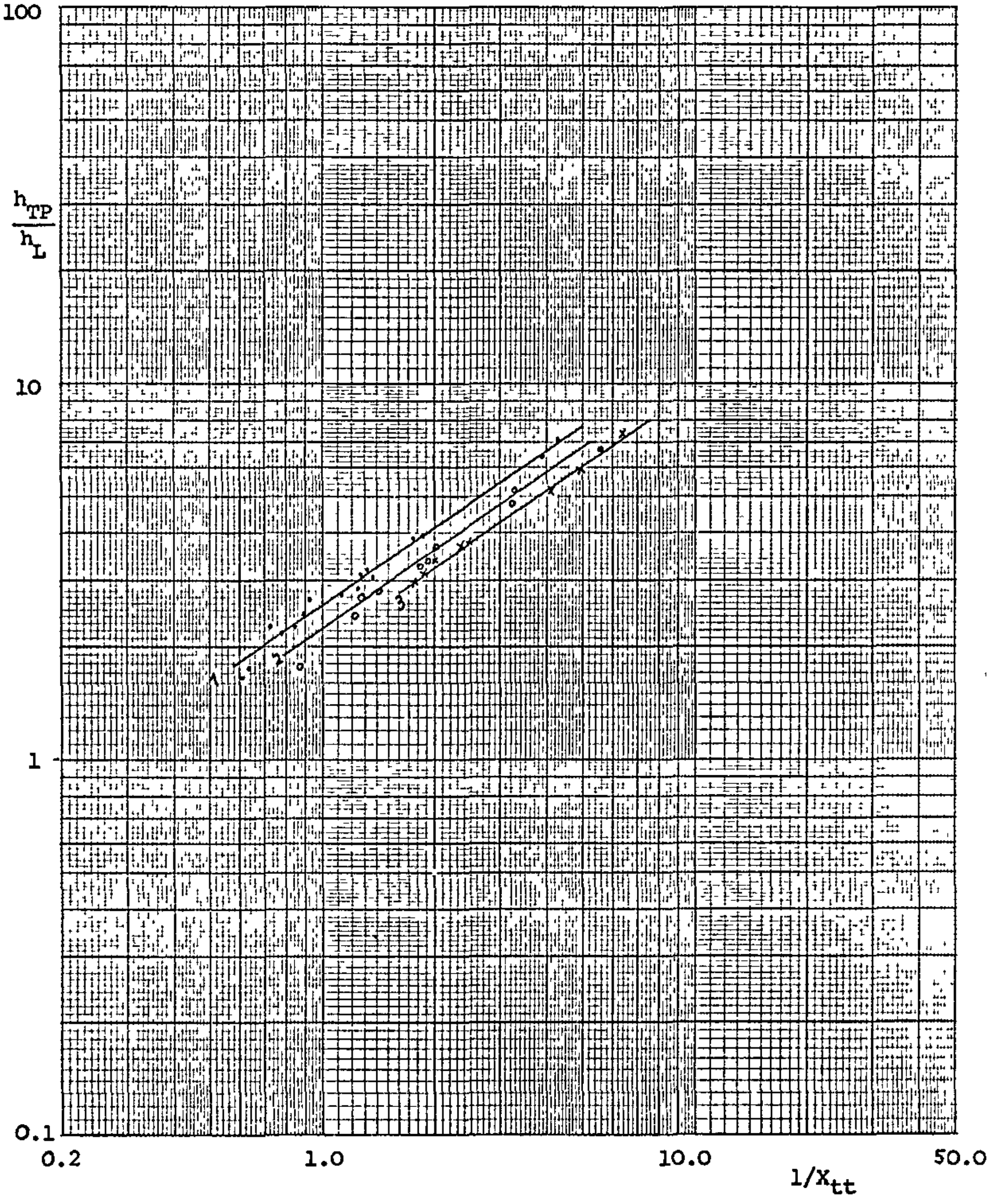

Fig. 5.3. Local ratio h_{TP}/h_L versus $1/X_{tt}$ for three ranges of the homogeneous Froude number Fr.

• 1. Fr = 1000-1100
∘ 2. Fr = 2200-2300
x 3. Fr = 3400-3600

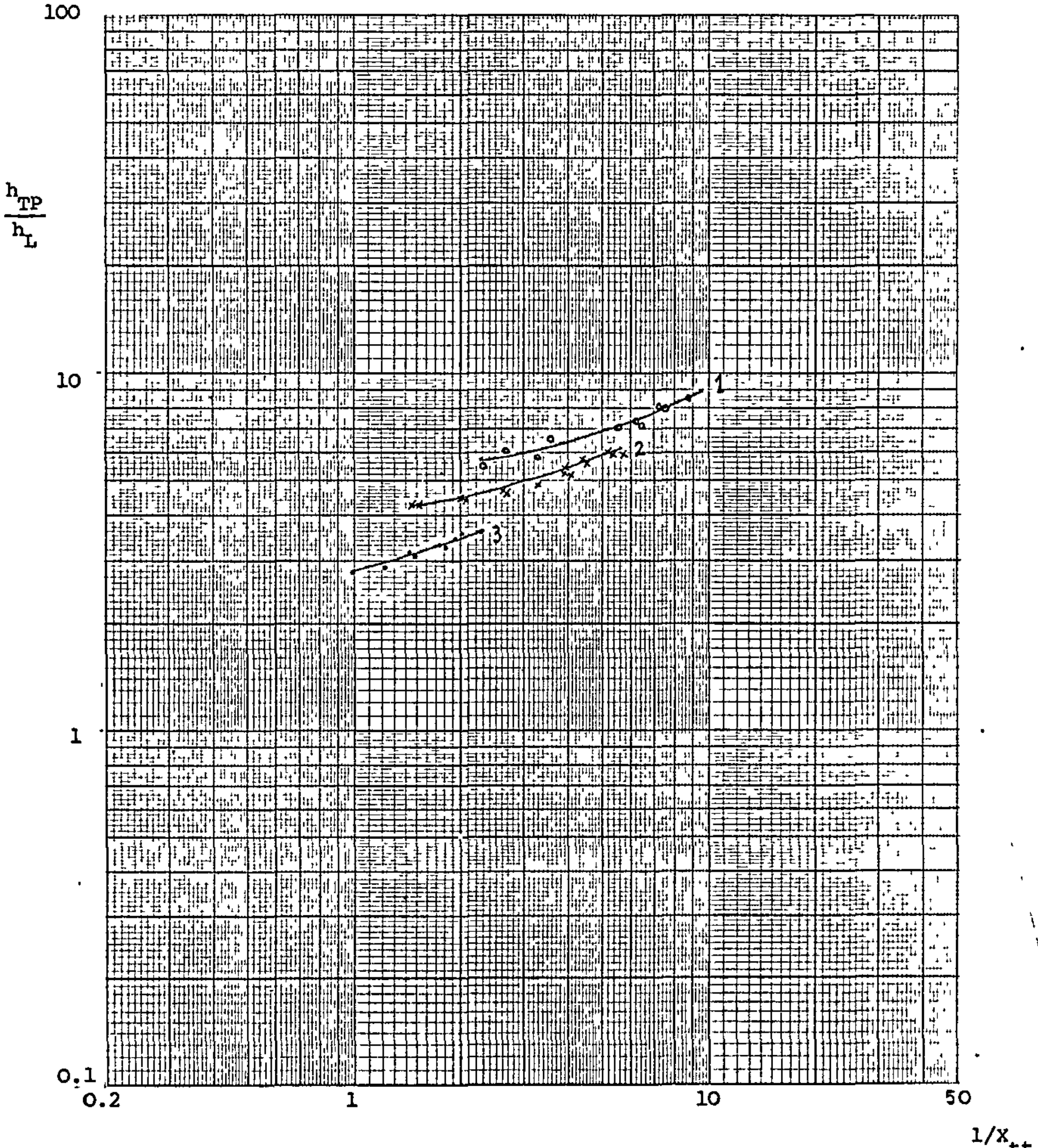

Fig. 5.4. Local ratio h_{TP}/h_L versus $1/X_{tt}$ for three ranges of the liquid Froude number Fr_L

∘ 1. Fr_L = 0.050-0.055

× 2. Fr_L = 0.100-0.120

• 3. Fr_L = 0.58-0.60

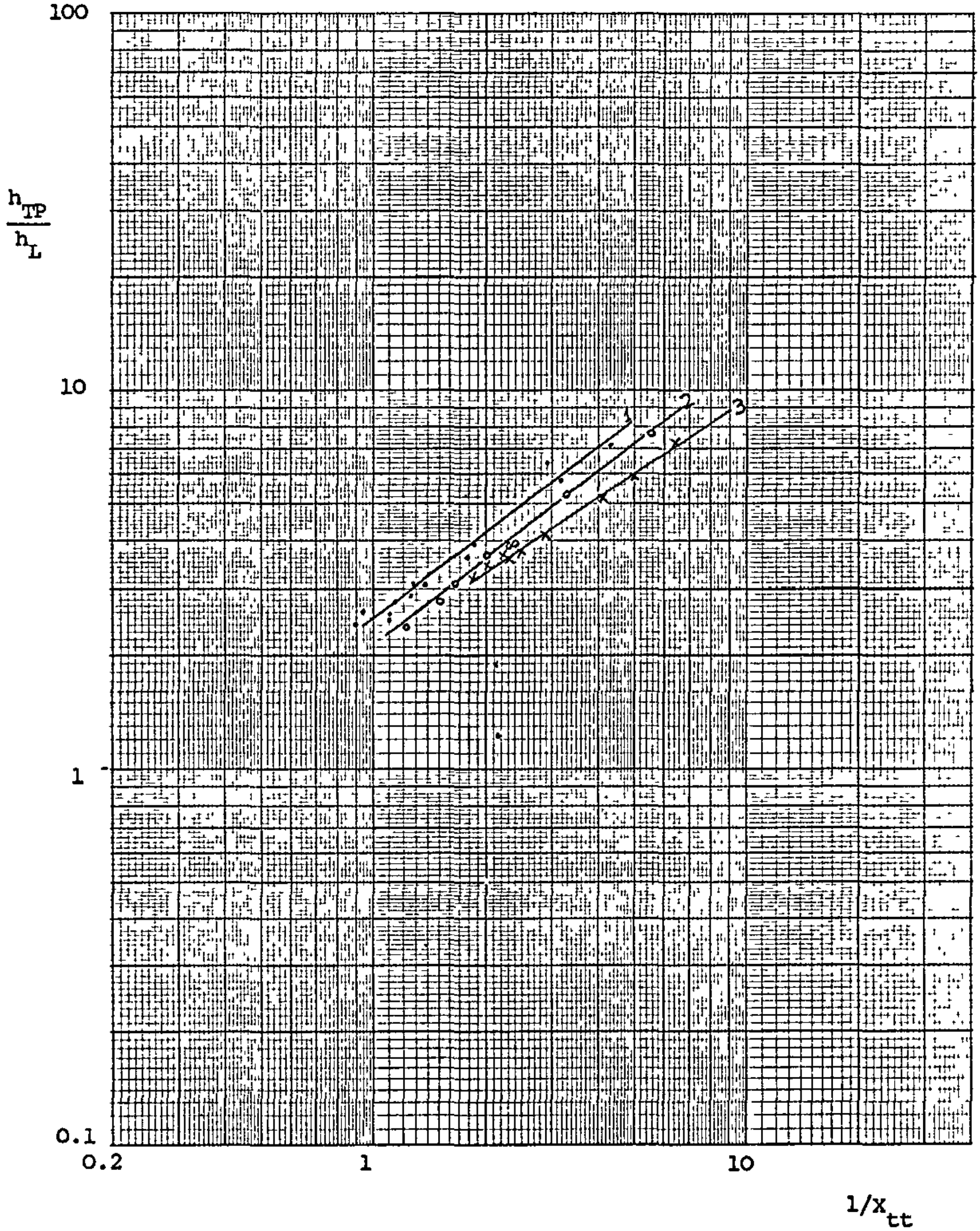

Fig. 5.5. Local ratio h_{TP}/h_L versus $1/X_{tt}$ for three ranges of the vapour Froude number Fr_g

• 1. Fr_g = 1000-1100

∘ 2. Fr_g = 2200-2300

× 3. Fr_g = 3400-3600

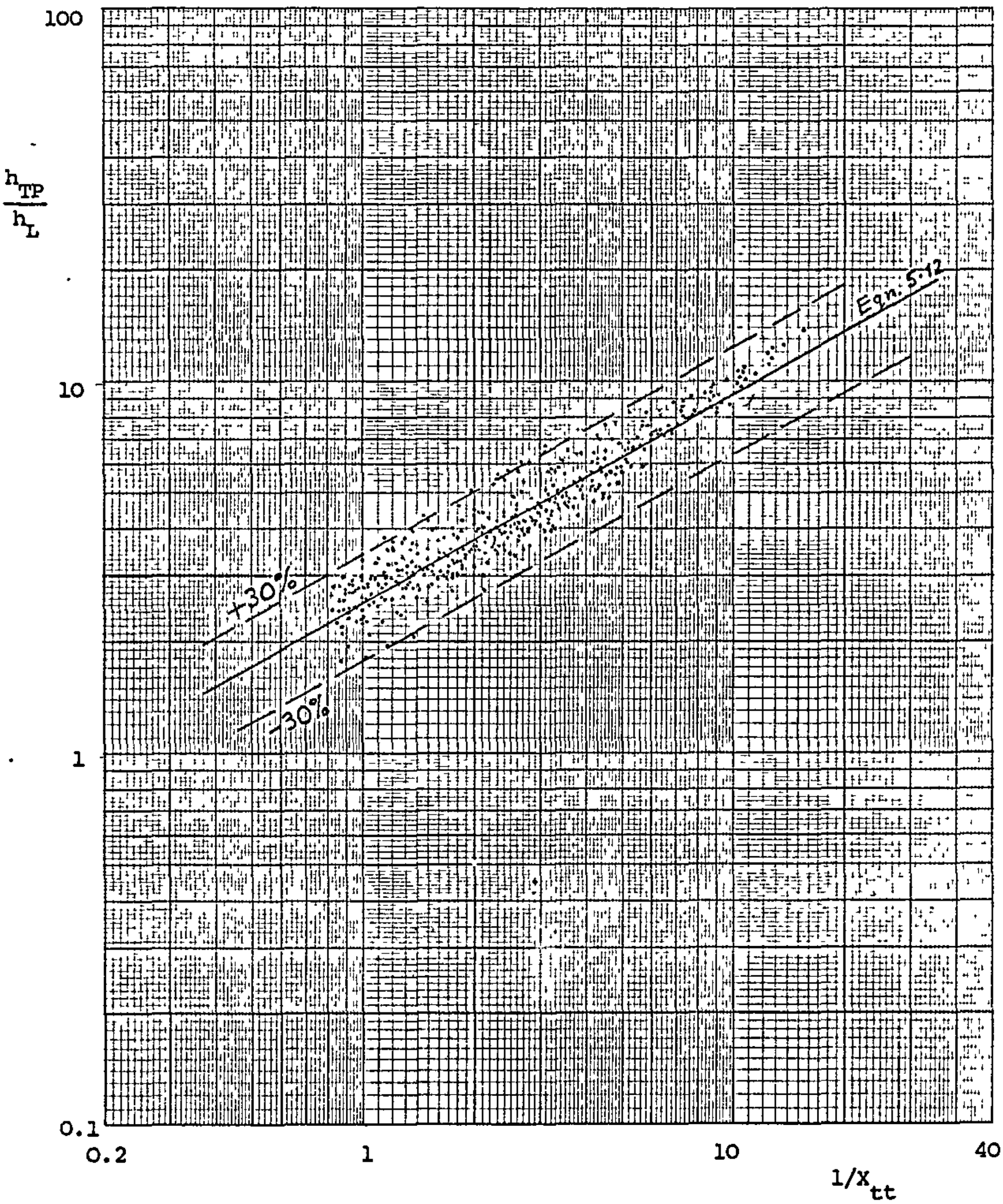

Fig. 5.6. Experimental local ratio $\frac{h_{TP}}{h_L}$ versus $1/X_{tt}$ (equation 5.12).

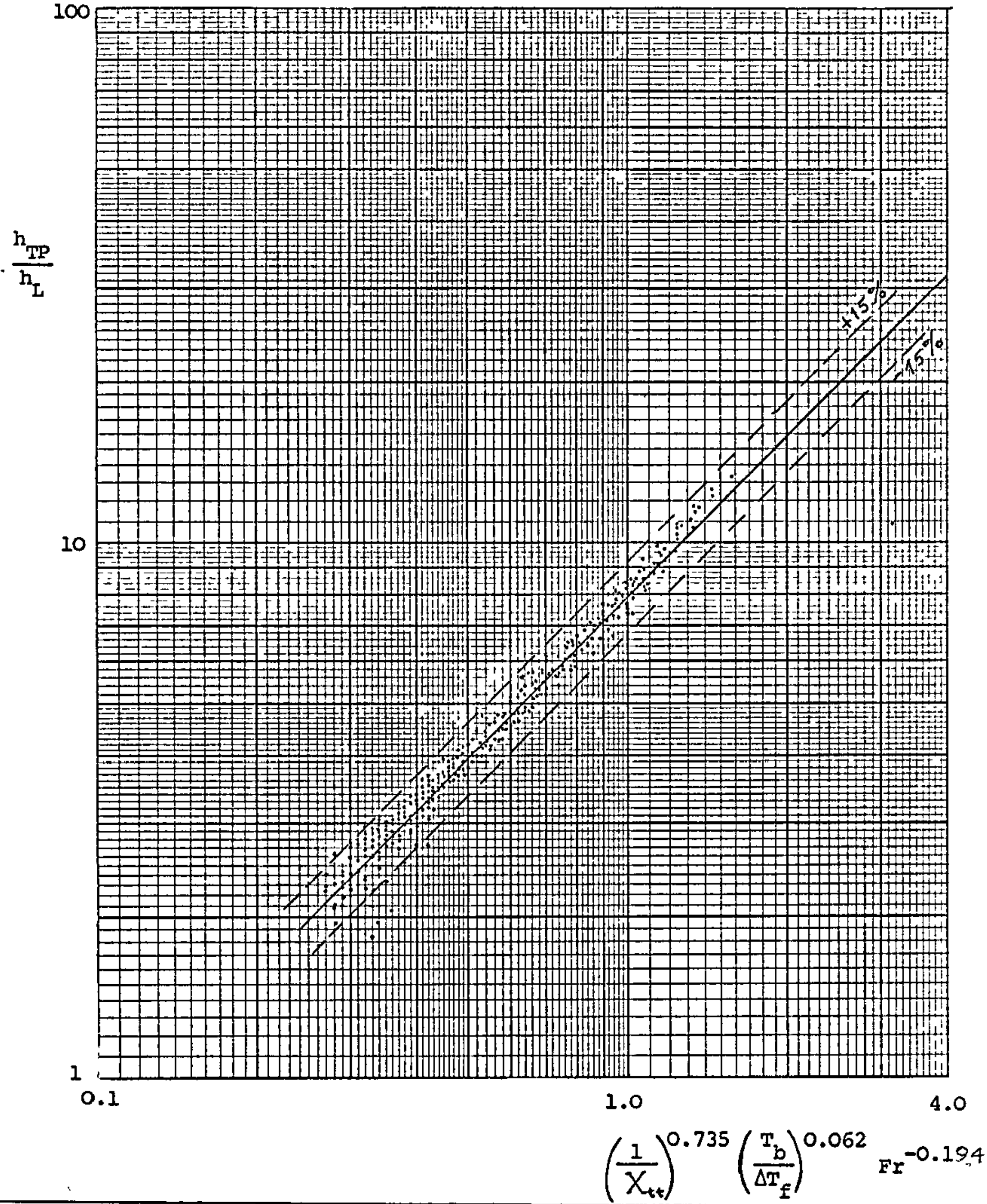

Fig. 5.7. Experimental local ratio $\frac{h_{TP}}{h_L}$ versus

$$\left(\frac{1}{X_{tt}}\right)^{0.735}\left(\frac{T_b}{\Delta T_f}\right)^{0.062} Fr^{-0.194}$$

(equation 5.13).

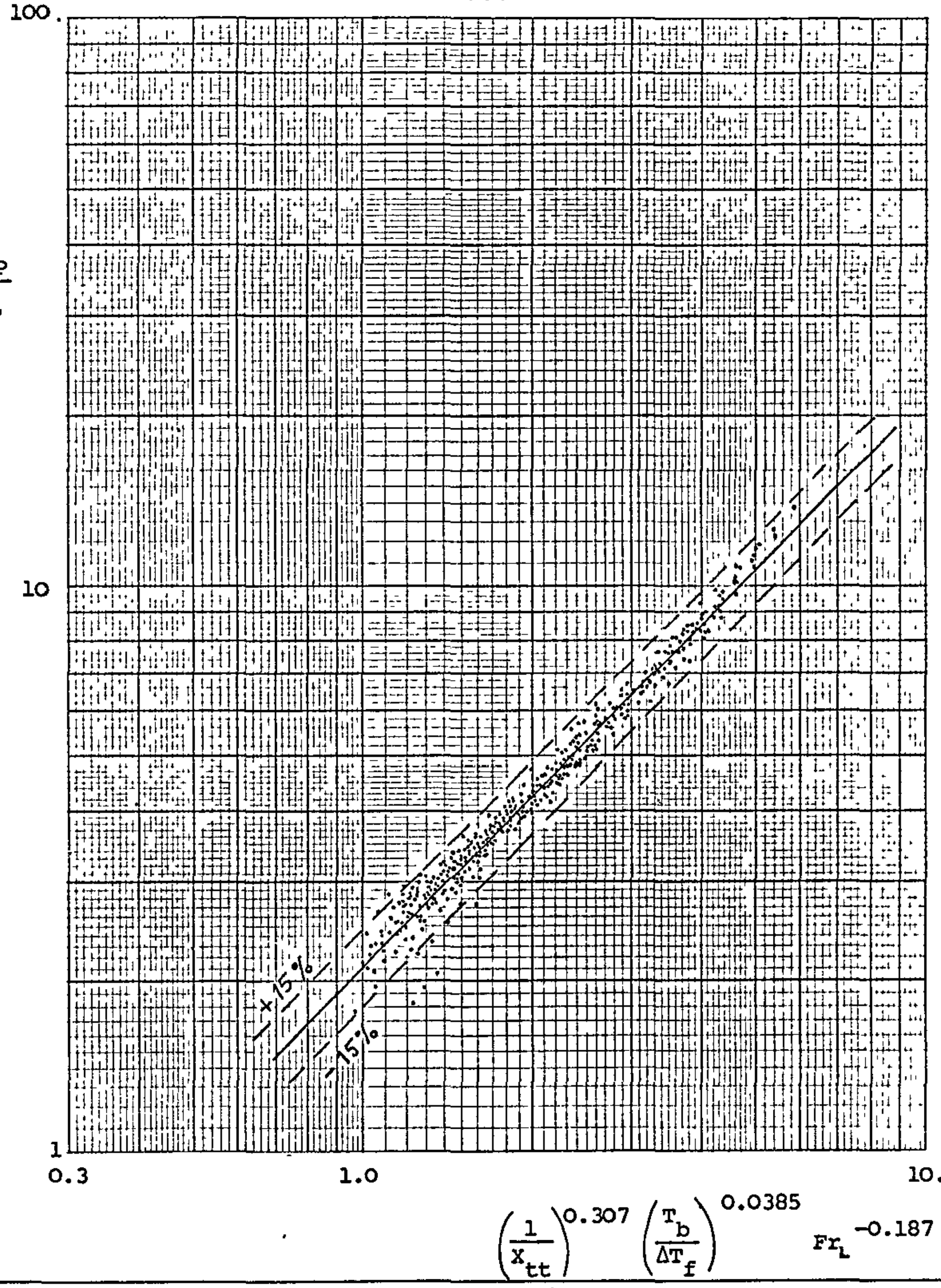

Fig. 5.8 Experimental local ratio $\frac{h_{TP}}{h_L}$ versus

$$\left(\frac{1}{X_{tt}}\right)^{0.307}\left(\frac{T_b}{\Delta T_f}\right)^{0.0385} Fr_L^{-0.187} \quad \text{(equation 5.14).}$$

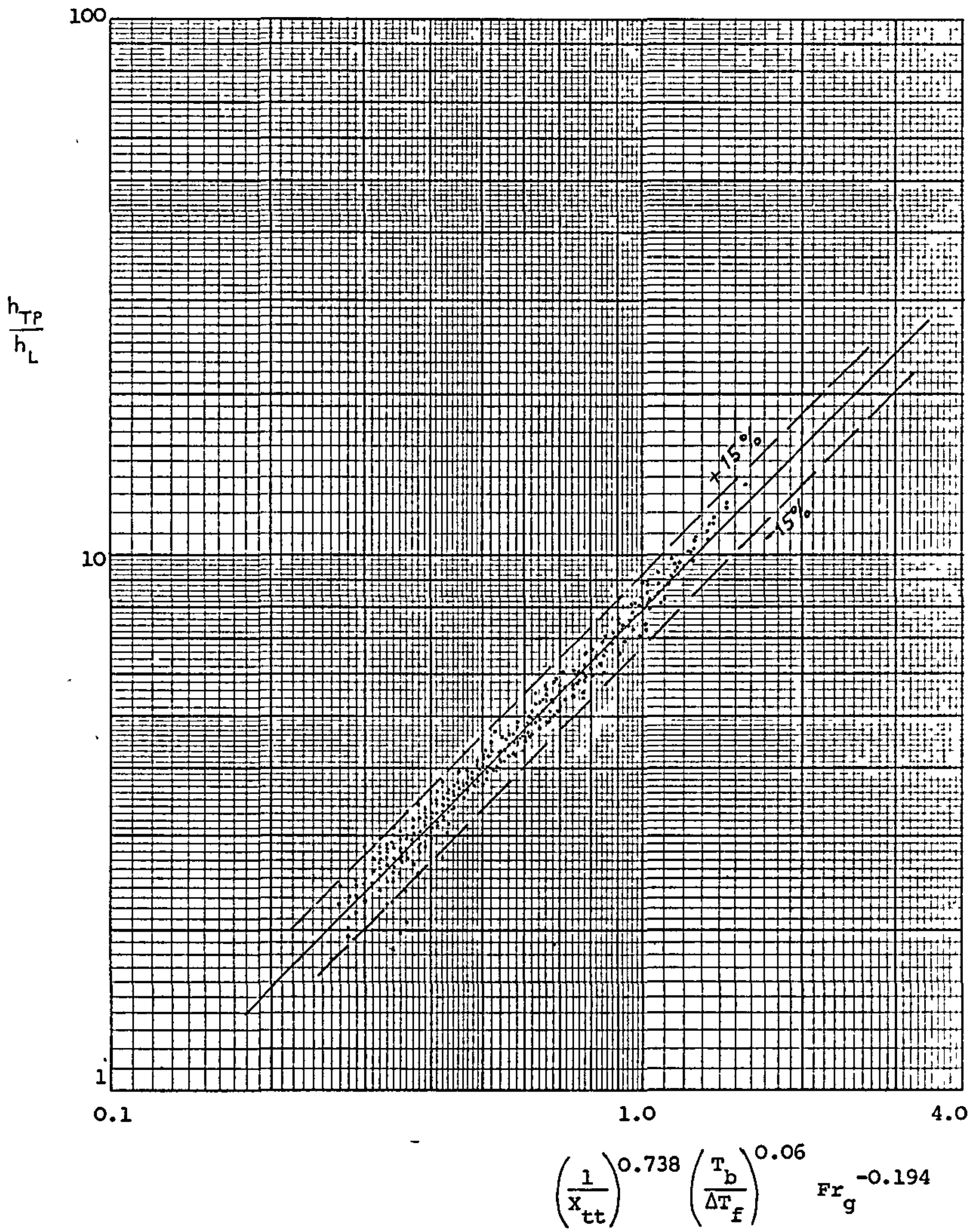

Fig. 5.9 Experimental local ratio $\frac{h_{TP}}{h_L}$ versus $\left(\frac{1}{X_{tt}}\right)^{0.738}\left(\frac{T_b}{\Delta T_f}\right)^{0.06} Fr_g^{-0.194}$ (equation 5.15).

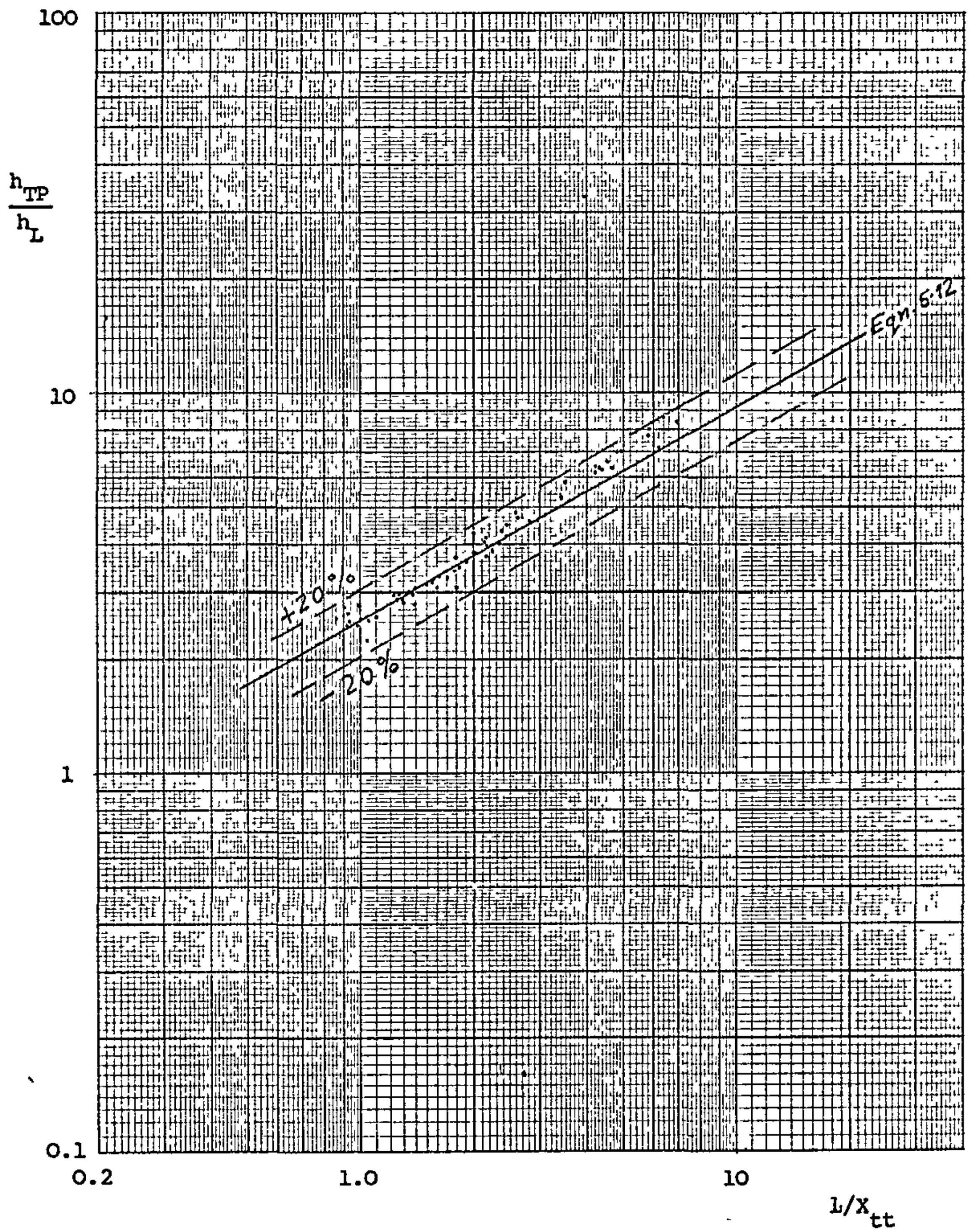

Fig. 5.10. Experimental length-mean ratio $\frac{h_{TP}}{h_L}$ versus $\frac{1}{X_{tt}}$ (equation 5.12).

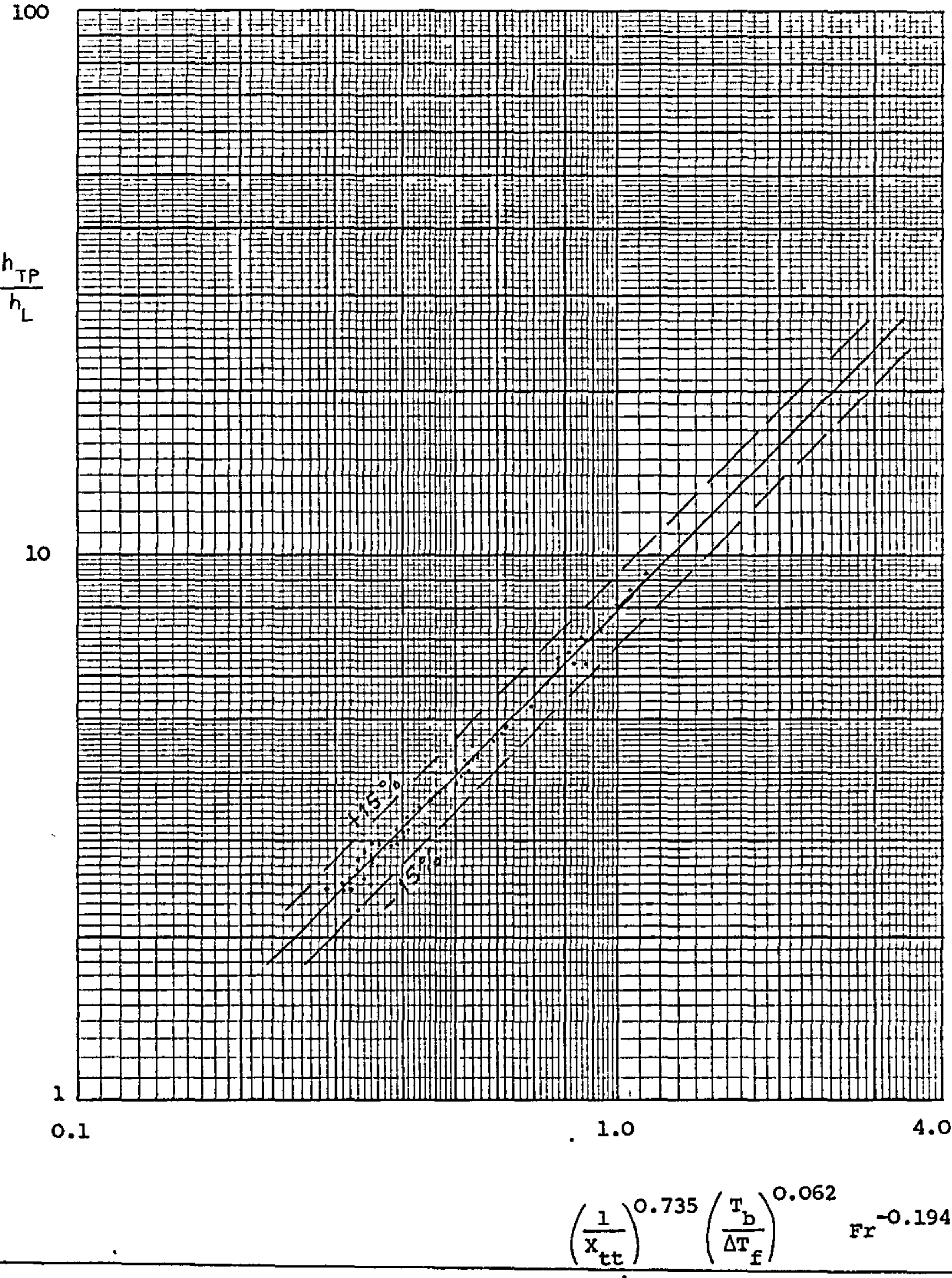

Fig. 5.11. Experimental length-mean ratio $\frac{h_{TP}}{h_L}$ versus

$$\left(\frac{1}{X_{tt}}\right)^{0.735} \left(\frac{T_b}{\Delta T_f}\right)^{0.062} Fr^{-0.194} \quad \text{(equation 5.13).}$$

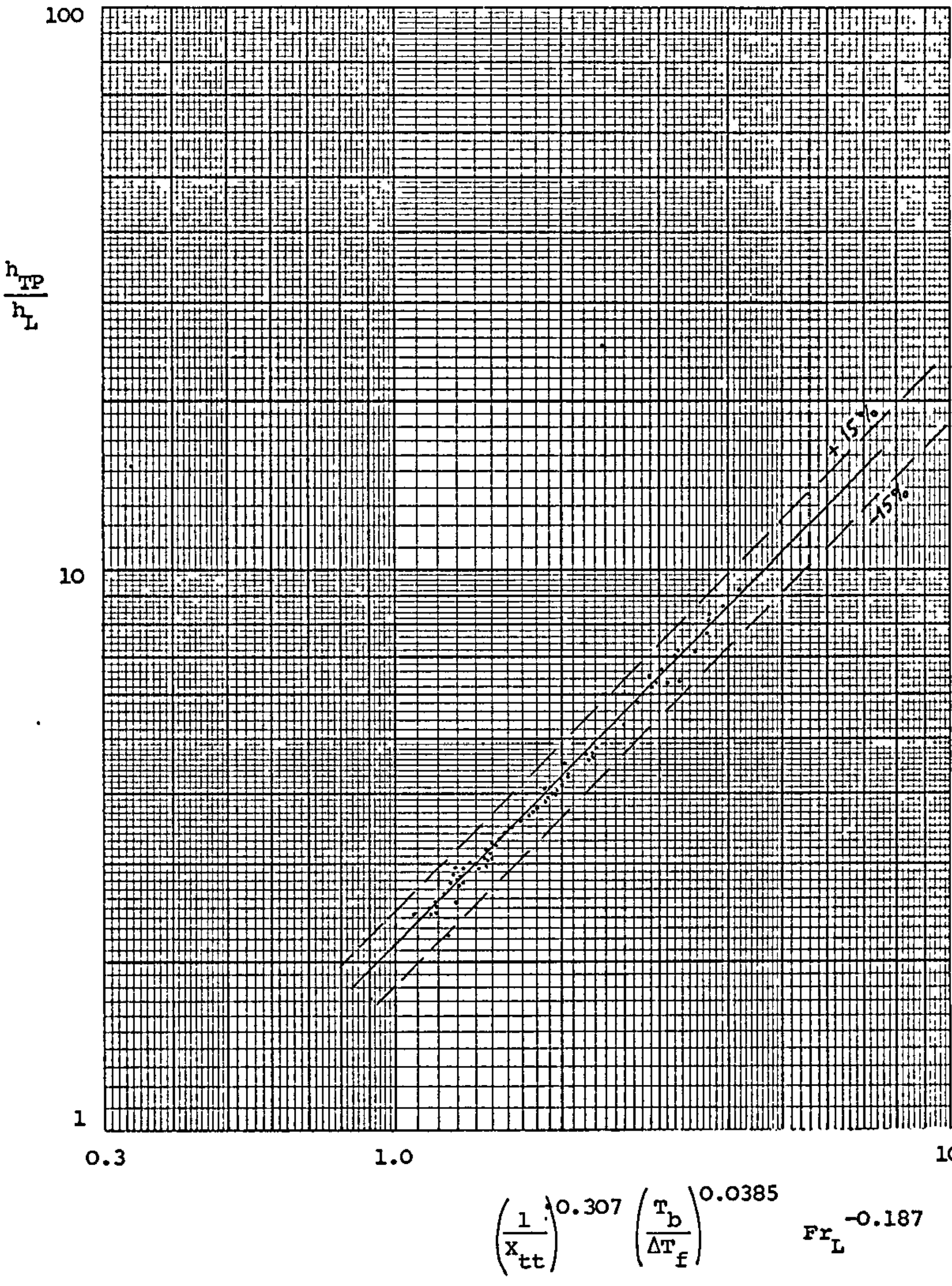

Fig. 5.12. Experimental length-mean ratio $\frac{h_{TP}}{h_L}$ versus

$$\left(\frac{1}{X_{tt}}\right)^{0.307}\left(\frac{T_b}{\Delta T_f}\right)^{0.0385} \quad Fr_L^{-0.187} \qquad \text{(equation 5.14).}$$

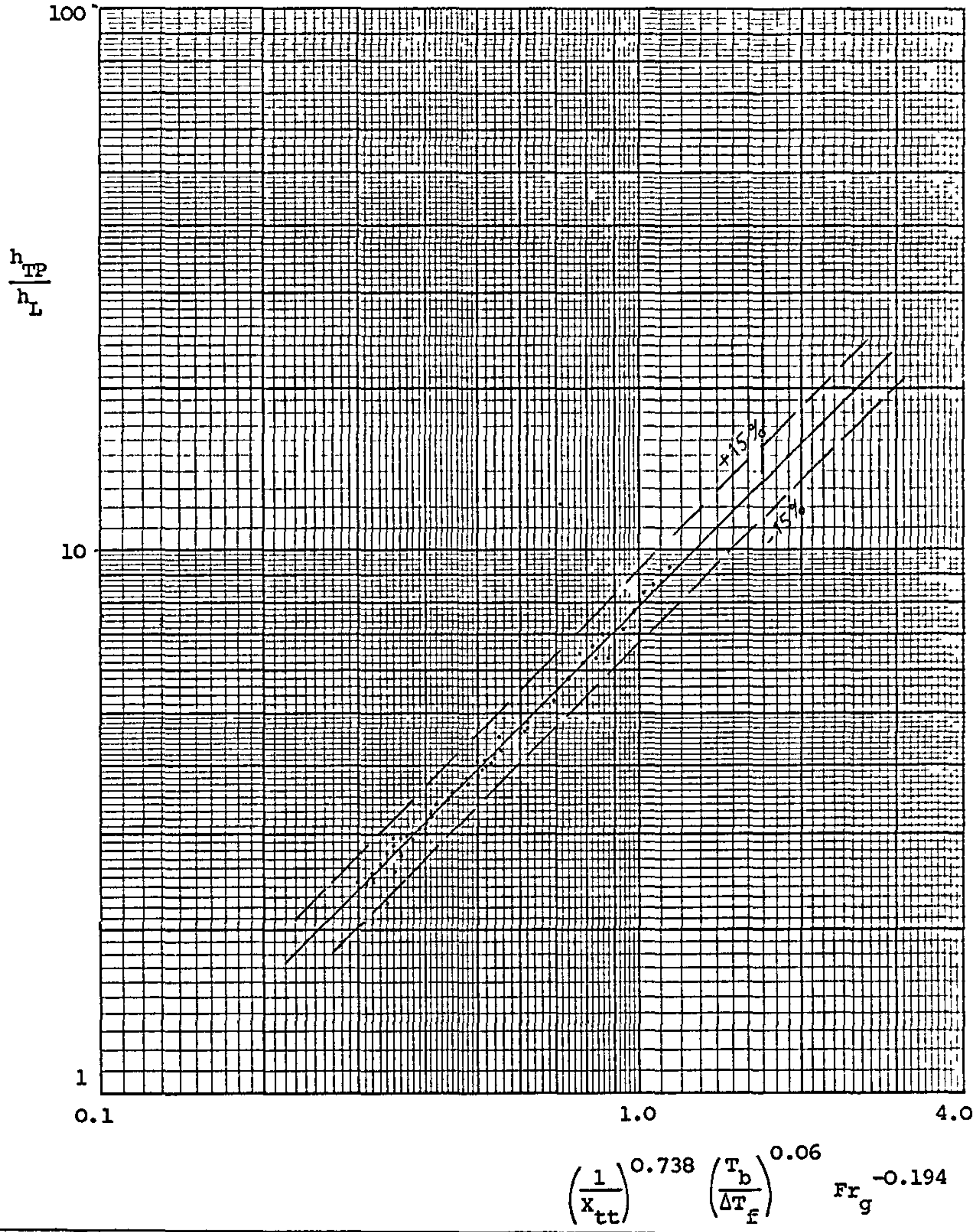

Fig. 5.13. Experimental length-mean ratio $\frac{h_{TP}}{h_L}$ versus

$\left(\frac{1}{X_{tt}}\right)^{0.738}\left(\frac{T_b}{\Delta T_f}\right)^{0.06} Fr_g^{-0.194}$ (equation 5.15).

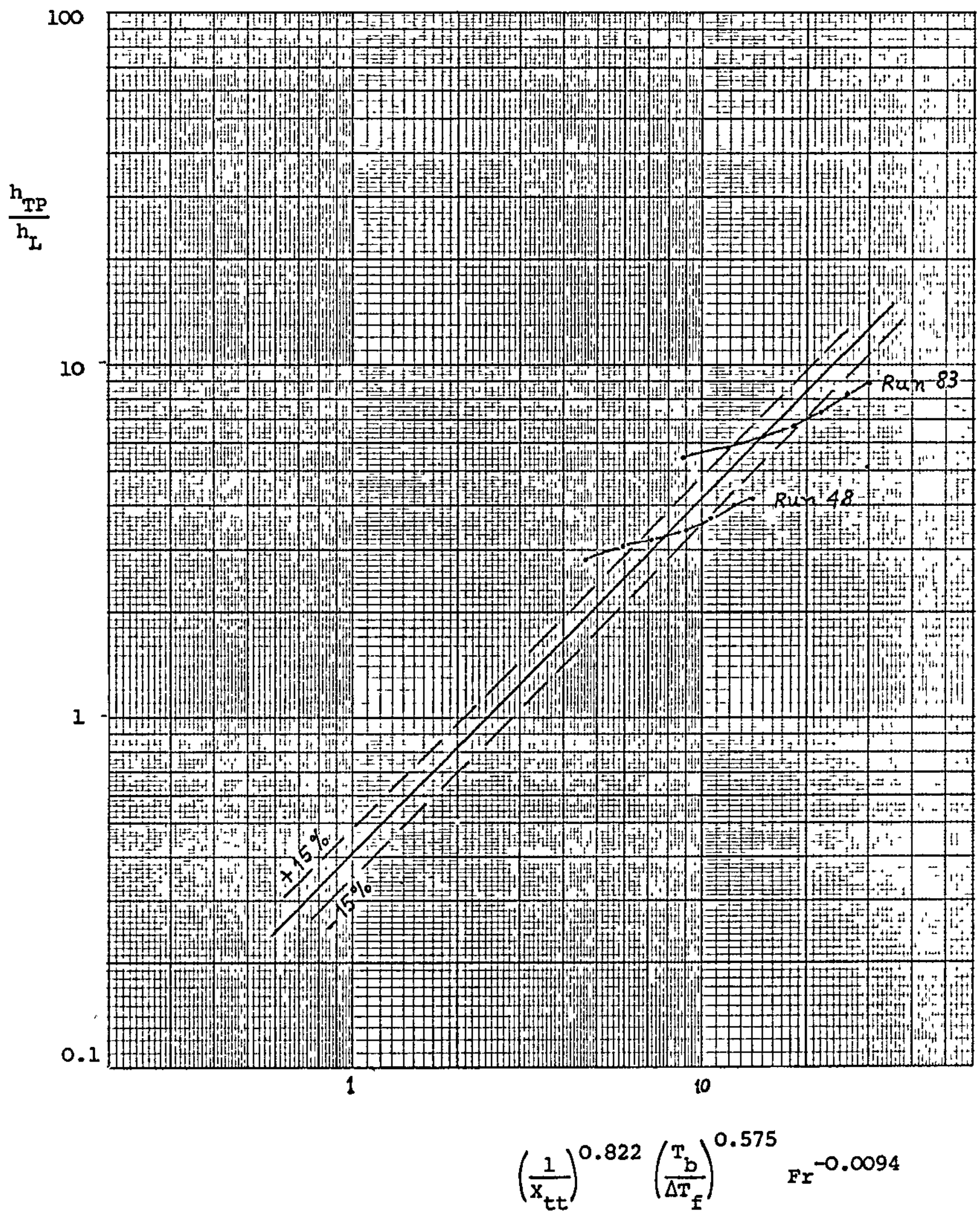

Fig. 5.14. Comparison of local heat transfer coefficients with the predictions of equation 5.16.

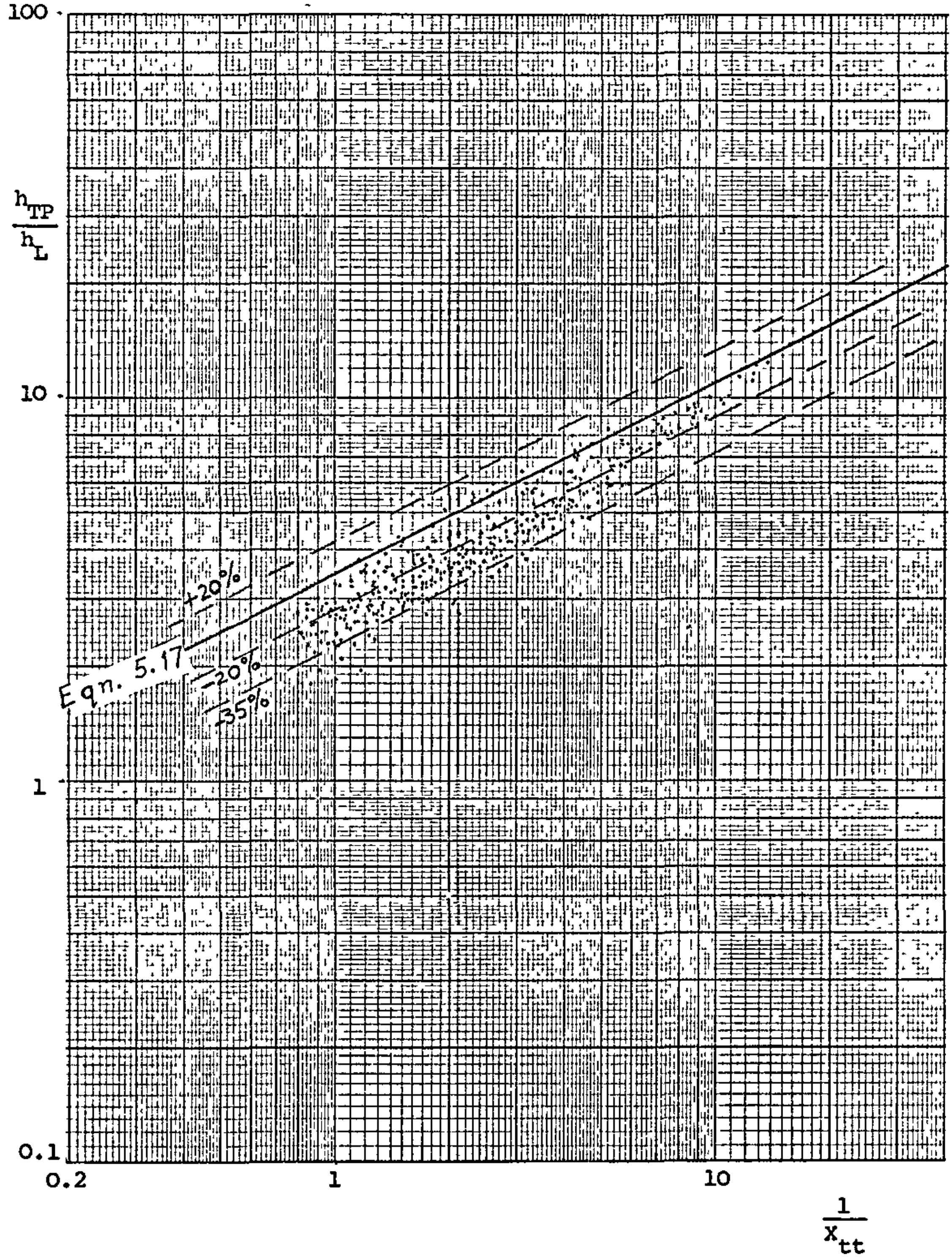

Fig. 5.15. Comparison of experimental local $\frac{h_{TP}}{h_L}$ with the predictions of Dengler-Addoms' correlation.

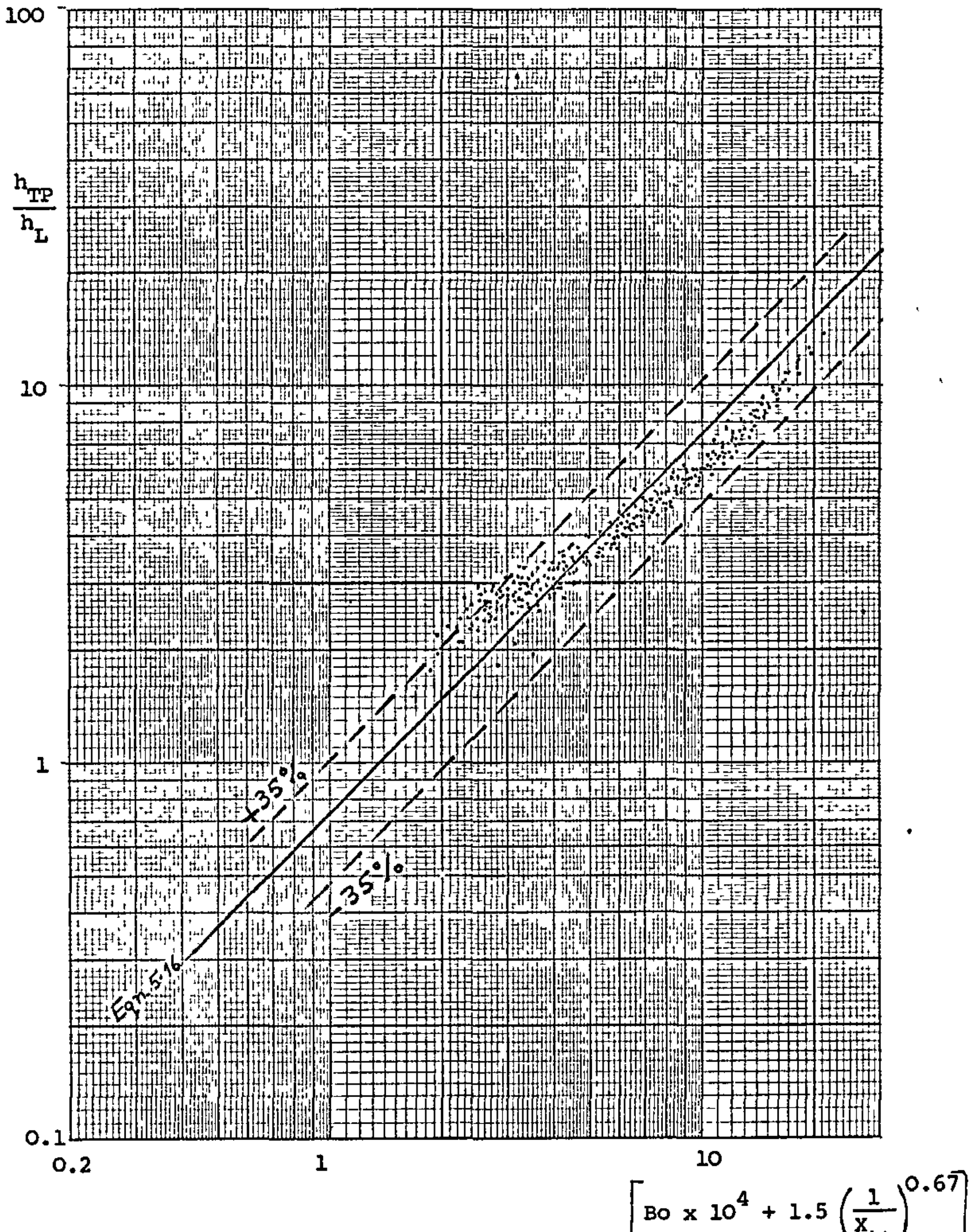

Fig. 5.16. Comparison of experimental local $\frac{h_{TP}}{h_L}$ with the predictions of Schrock-Grossman's correlation.

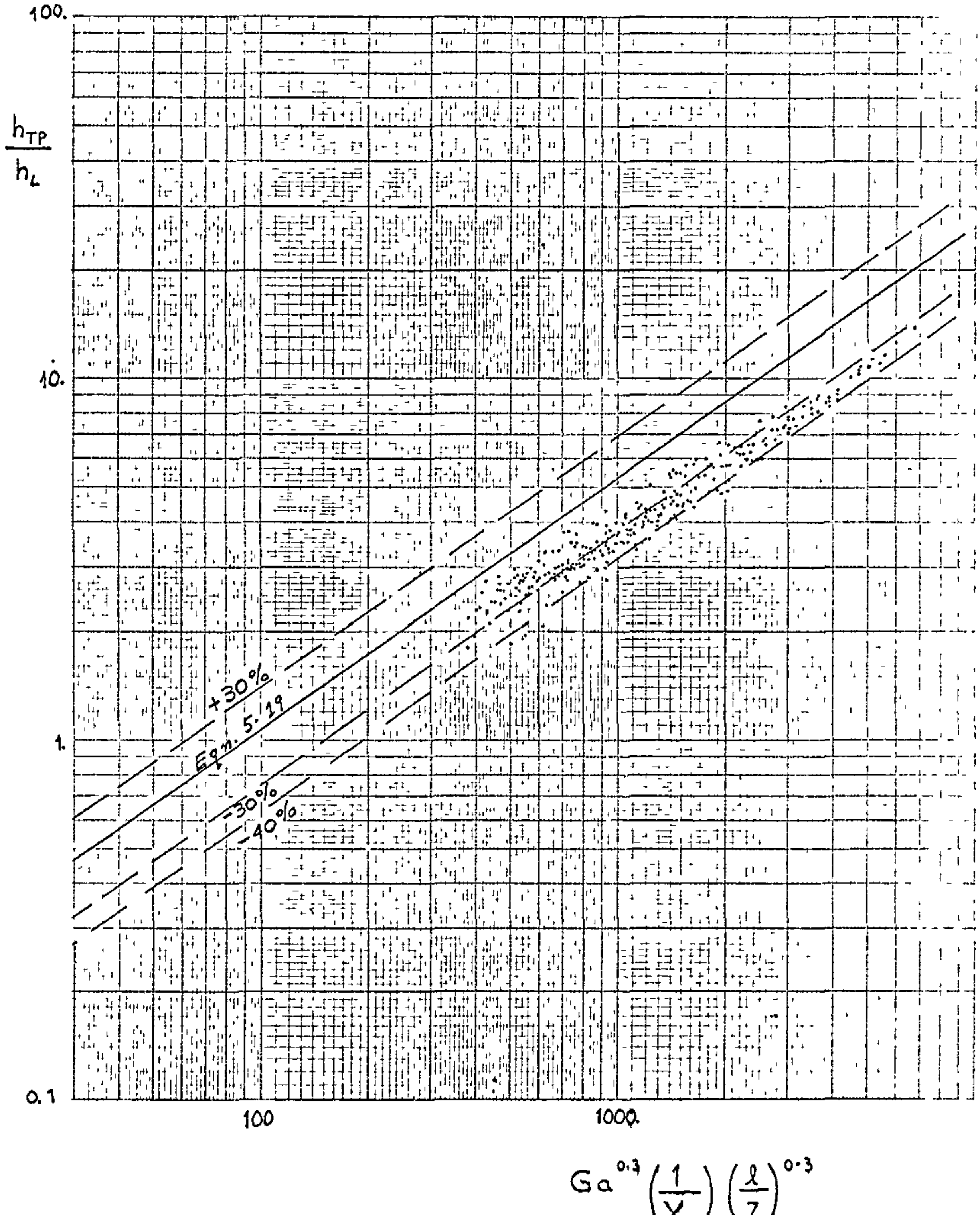

Fig. 5.17 Comparison of experimental results with the predictions of Abid's correlation.

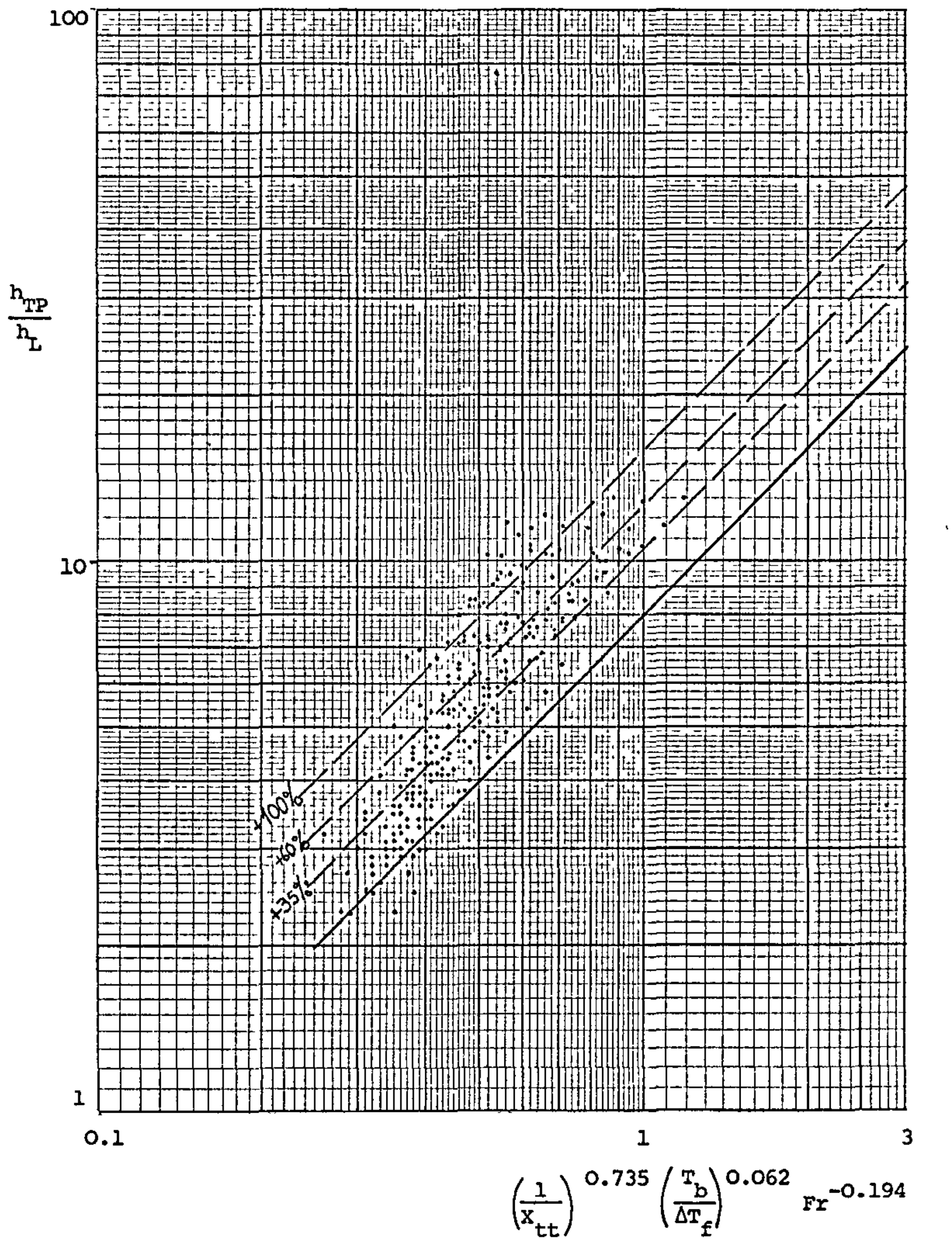

Fig. 5.18. Comparison of local heat transfer data of reference A1 with the predictions of equation 5.13.

6. Conclusions

Experiments were conducted on a steam-heated natural circulation reboiler tube 0.872 in. I.D. using water as a test liquid. Local and length-mean heat transfer coefficients were determined. The local heat transfer data revealed the occurrence of the nucleate and convective regimes of heat transfer along the tube. Only the local data points in which the convective mechanism was believed to be predominant were used for correlating purposes.

The analysis of local heat transfer data in the convective region indicated that the Froude number is an important correlating parameter. Plots of the heat transfer ratio h_{TP}/h_L versus $1/X_{tt}$ showed that at a constant value of $1/X_{tt}$, a decrease in the Froude number corresponds to an increase in h_{TP}/h_L. Froude number, being a relationship between inertia and gravity forces, is thought to account for the effect of these forces on the film thickness and the thermal resistance of the liquid film in annular two phase flow.

The Lockhart Martinelli parameter is an established correlating factor for two phase heat transfer coefficients. The film temperature difference is also a strong correlating parameter in thermosiphon reboilers. Attempts were made to correlate heat transfer coefficients in terms of these two parameters and the Froude number. Three forms of Froude number were used: based on the homogeneous velocity, the liquid superficial velocity and the vapour superficial velocity. Correlations based on each one of these forms were proposed (equations 5.13, 5.14 and 5.15). These equations correlated the present data to within ±15%, the correlation based on the vapour Froude number giving slightly better accuracy than the other two. Equations 5.13, 5.14 and 5.15 proved to be an improvement on the literature equation 5.12, which correlated the data to within ±30%.

The equations developed are valid in the range of local qualities from 2% to 33.8%. The local homogeneous and vapour phase Froude numbers ranged from about 300 to 9200.

The length-mean heat transfer coefficients for the length-mean qualities between 2 and 17.5% were also correlated by equations 5.13, 5.14 and 5.15 to within ±15%.

The agreement between the present local data and the predictions of Dengler-Addoms' correlation, Schrock-Grossman's correlation and Abid's correlation is reasonably good.

The agreement of the proposed correlation with data of reference A1 is not so good. Only the points from the lower heat flux experiments respond to the method of correlation developed here. This is attributed to the restricted range of qualities and heat fluxes used in the present work.

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APPENDIX I

Physical Properties

I.1. Physical properties of water and steam

Physical properties for the water/steam system are given in Tables I.1, I.2 and I.3. These values are taken from reference S2.

Table I.1

Density, enthalpy and saturation pressure of water and steam as a function of the saturation temperature in the range from 99°C to 106°C. (SI units)

T_{SAT}, °C	P_{SAT}, bar	ρ_L, kg/m³	ρ_g, kg/m³	H_L, KJ/kg	H_g, KJ/kg
99	0.9776	958.86	0.5780	414.85	2674.4
100	1.0133	958.13	0.5977	419.06	2676.0
101	1.0500	957.39	0.6180	423.28	2677.6
102	1.0878	956.66	0.6388	427.50	2679.1
103	1.1267	955.93	0.6601	431.73	2680.7
104	1.1668	955.20	0.6821	435.95	2682.2
105	1.2080	954.47	0.7047	440.17	2683.7
106	1.2504	953.74	0.7277	444.40	2685.3

Table I.2

Viscosity, thermal conductivity and Prandtl number of water and steam at saturation as a function of T_{SAT} in the range from 90°C to 110°C

T_{SAT}, °C	$\mu_L \times 10^6$ $\frac{kg}{sec\ m}$	$\mu g \times 10^6$ $\frac{kg}{sec\ m}$	$k_L \times 10^2$ $\frac{W}{m^oC}$	$k_g \times 10^2$ $\frac{W}{m^oC}$	Pr_L	Pr_g
90	311	11.62	67.6	2.40	1.94	0.966
100	279	12.02	68.1	2.48	1.73	0.984
110	252	12.42	68.4	2.56	1.56	1.000

Table I.3

Latent heat of evaporation of water in the temperature range from 110°C to 150°C

T_s °C	110	115	120	125	130	135	140	145	150	155
H'_{Lg} KJ/Kg	2230.0	2216.2	2202.2	2188.0	2173.6	2158.9	2144.0	2128.7	2113.2	2097.4

Tables I.1 and I.2 cover the temperature range used in the boiling experiments. Table I.3 covers the range of steam temperature in the heating jackets. All physical properties used in the calculations are values at the measured bulk fluid temperature.

To facilitate the use of physical properties in computer calculations, linear interpolation formulas have been constructed. These formulas represent straight lines of best fit for each property in the temperature ranges considered.

I.1.1. Saturation curve, P_{SAT}, T_{SAT}

$$T_{SAT} = 74.0221 + 25.6825 \, P_{SAT}$$

where T_{SAT} is in °C and P_{SAT} in [bar]

I.1.2. Density of liquid, ρ_L

$$\rho_L = 1032.069 - 0.7393 \, T_{SAT} \quad [kg/m^3, °C]$$

or

$$\rho_L = 65.252 - 0.02564 \, T_{SAT} \quad [lb/ft^3, °F]$$

I.1.3. Density of water vapour, ρ_g

$$\rho_g = 1.6004 + 0.02197\ T_{SAT} \qquad [kg/m^3,\ ^{o}C]$$

or

$$\rho_g = -0.12429 + 0.000762\ T_{SAT} \qquad [lb/ft^3,\ ^{o}F]$$

I.1.4. Enthalpy of liquid, H_L

$$H_L = -3.1986 + 4.2226\ T_{SAT} \qquad [KJ/kg,\ ^{o}C]$$

or

$$H_L = -33.6472 + 1.0085\ T_{SAT} \qquad [BTU/lb,\ ^{o}F]$$

I.1.5. Enthalpy of water vapour, H_g

$$H_g = 2522.03 + 1.54\ T_{SAT} \qquad [KJ/kg,\ ^{o}C]$$

or

$$H_g = 1056.94 + 0.8556\ T_{SAT} \qquad [BTU/lb,\ ^{o}F]$$

I.1.6. Latent heat of evaporation, H_{Lg} in the range of the boiling experiments (99 to 106°C)

$$H_{Lg} = H_g - H_L$$

$$H_{Lg} = 2525.2 - 2.6826\ T_{SAT} \qquad [KJ/kg,\ ^{o}C]$$

or

$$H_{Lg} = 1085.69 - 0.64074\ T_{SAT} \qquad [BTU/lb,\ ^{o}F]$$

I.1.7. Viscosity of liquid, μ_L

$$\mu_L = 5.74 \times 10^{-4} - 2.954 \times 10^{-6}\ T_{SAT} \qquad [\frac{kg}{sec\ m},\ ^oC]$$

$$\mu_L = 1.5171 - 0.00397\ T_{SAT} \qquad [\frac{lb}{ft\ hr},\ ^oF]$$

I.1.8. Viscosity of water vapour, μ_g

$$\mu_g = 8.644 \times 10^{-6} + 3.44 \times 10^{-8}\ T_{SAT} \qquad [\frac{kg}{sec\ m}]$$

$$\mu_g = 0.01944 + 4.583 \times 10^{-5}\ T_{SAT} \qquad [\frac{lb}{ft\ hr},\ ^oF]$$

I.1.9. Thermal conductivity of liquid, k_L

$$k_L = 0.6491 + 0.000316\ T_{SAT} \qquad [\frac{Watt}{m\ ^oC},\ ^oC]$$

$$k_L = 0.3717 + 0.0001015\ T_{SAT} \qquad [\frac{BTU}{hr\ ft\ ^oF},\ ^oF]$$

I.1.10. Prandtl number of liquid, Pr_L

$$Pr_L = 3.965 - 0.01053\ T_{SAT} \qquad [^oF]$$

I.1.11. Latent heat of evaporation, H'_{Lg}, in the temperature range of the heating jackets, 110 to 155^{o}C

$$H'_{Lg} = 2555.2 - 2.9429\ T_{SAT} \qquad [KJ/kg,\ ^oC]$$

$$H'_{Lg} = 1121.106 - 0.70294\ T_{SAT} \qquad [BTU/lb,\ ^oF]$$

I.2. Physical properties of the test section material

Only the thermal conductivity of the tube, made of steel 316, is of use in these calculations. It is given in reference A1:

$$k_s = 9.15 + 0.0066\ T \qquad [\frac{BTU}{hr\ ft^{o}F}\ ,\ ^{o}C]$$

where T is the mean wall temperature, taken as the average between the steam temperature and the bulk fluid temperature on the boiling side.

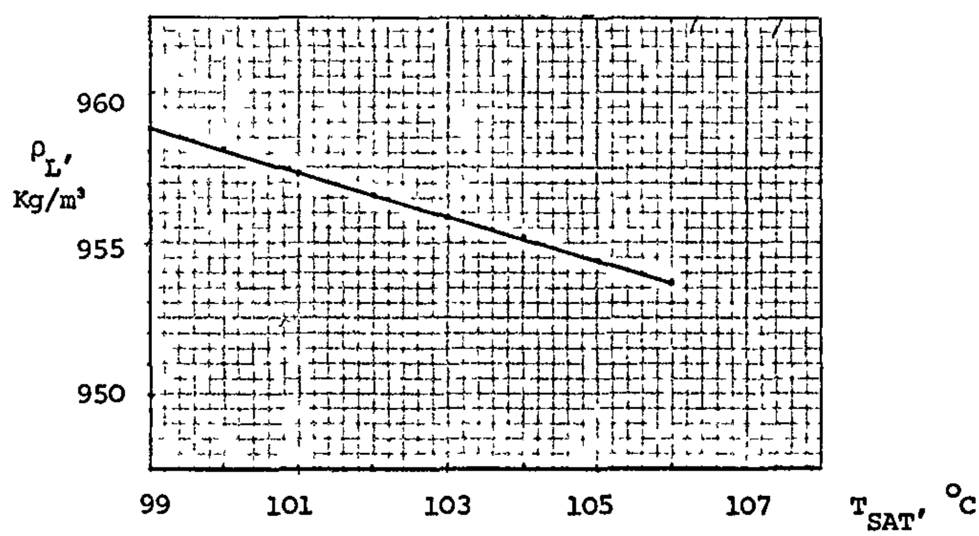

Fig. I.1. Density of water.

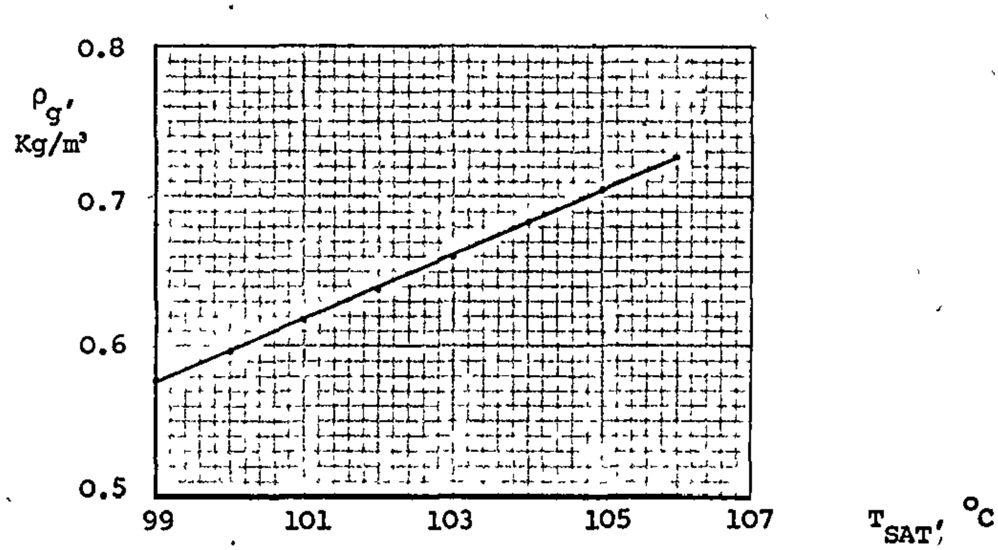

Fig. I.2. Density of steam.

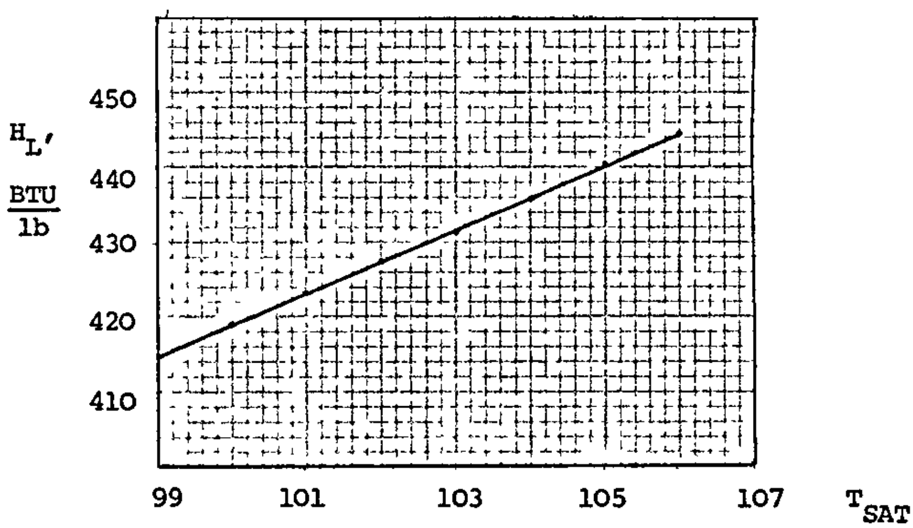

Fig. I.3. Enthalpy of water.

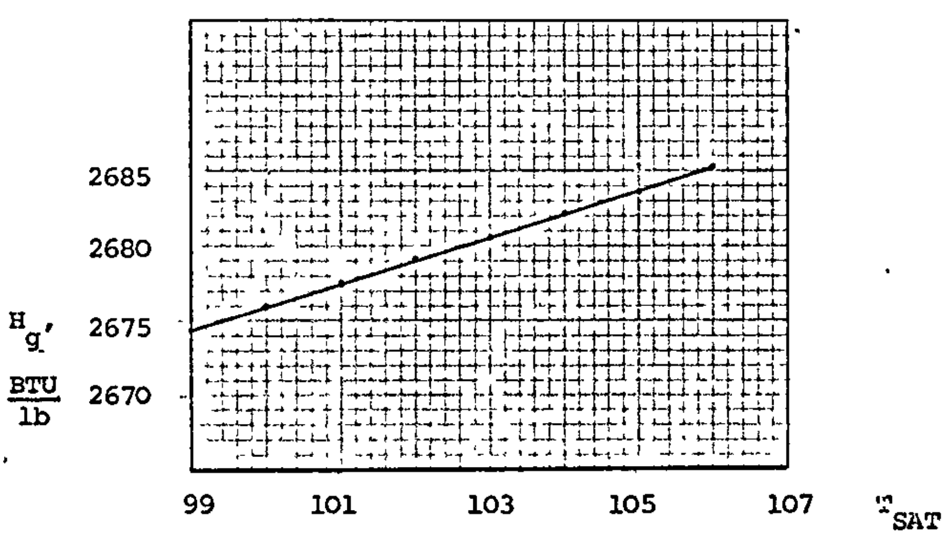

Fig. I.4. Enthalpy of steam.

Appendix II

Thermocouple Calibration

The ten thermocouples used to measure the liquid temperature in the reboiler were compared with an NPL-tested thermometer (A) at the boiling point of distilled water. Cold junction temperatures were measured by a BSI tested thermometer (B). Five comparison tests were made.

Table II.1 shows the particulars of both thermometers. Table II.2 summarises the conditions under which the tests were made. The detailed results of the tests and the final corrections to the thermocouple readings are given in Table II.3. The calibration calculations are explained by means of an example, taken from test No. 1.

II.1. The true temperature of the boiling water at the depth of 100mm, T_m

Thermometer reading: 100.5°C

1st correction: -0.05°C (from test certificate)

2nd correction: (due to the exposed column of mercury) is calculated from the expression:

$$KN(t-T), \quad \text{where}$$

$K = 0.0016\ (^{\circ}C)^{-1}$ (thermal expansion constant)

$N = 4.3^{\circ}C$ (length of the exposed column).

Table II.1

-	Thermometer A	Thermometer B
No.	74239 NPL 74	90440 BST 74
Date of Test	17 June 1974	12 December 1974
Name on Thermometer	H.S.	H.S.
Specification	BS 593/54 A130C/100	BS 593/54 A70C/100
Range	$-0.5^{\circ}C$ to $+0.5^{\circ}C$	$-0.5^{\circ}C$ to $+0.5^{\circ}C$
	$99.5^{\circ}C$ to $130.5^{\circ}C$	$39.5^{\circ}C$ to $70.5^{\circ}C$
Divided to	$0.1^{\circ}C$	$0.1^{\circ}C$
Immersion	100 mm	100 mm
Accuracy	$\pm 0.1^{\circ}C$	$\pm 0.05^{\circ}C$

Table II.2

-	Test 1	Test 2	Test 3	Test 4	Test 5
Atmospheric Pressure (mm Hg)	762.45	762.30	762.30	764.30	764.20
Reading of thermometer A immersed in boiling water ($^{\circ}C$)	100.5	100.5	100.5	100.6	100.55
Length of the exposed column expressed in $^{\circ}C$	4.3	4.3	4.3	4.4	4.35
Average reading of cold junction thermometer, $^{\circ}C$	43.755	43.74	43.76	43.65	43.75

t: temperature of air surrounding the exposed column during NPL test of the thermometer ($33^{\circ}C$)

T: temperature of steam around the exposed column in this experiment ($100^{\circ}C$).

Therefore: $KN(t-T) = -0.046^{\circ}C$.

Total correction: $-0.05 + (-0.046) = -0.096^{\circ}C$.

$Tm = 100.5 - 0.096 = 100.404^{\circ}C$.

II.2. Cold junction temperature, T_R

Average reading of thermometer B: 43.755°C

Corrections from the test certificate:

at 40.00°C ... +0.02°C

at 45.00°C ... +0.08°C

Interpolated correction: +0.065°C

Therefore $T_R = 43.755 + 0.065 = 43.82°C$.

In this case the correction due to the length of the exposed column of mercury, was negligible.

II.3. Temperature of the boiling water at a depth of 100 mm from the thermocouple measurement, T_c

Ten readings were taken for each thermocouple in each test and the average values are recorded in Table II.3. Cold junction temperatures were converted into e.m.f. by interpolation between the following values:

T, °C	43.0	44.0
V, mV	1.73	1.77

This gives, for the test No. 1 (when T = 43.82°C)

$$V = 1.7628 \text{ mV}.$$

This e.m.f. was added to the average for each thermocouple (Table 3) and converted into temperature by means of the equation.

$$T_c = 24.1382V + 1.06 \ (°C)$$

which is a straight line of best fit for the range 99°C to 106°C. The temperatures, T_c are recorded in Table 3.

II.4. Correction to thermocouple-measured temperatures

The difference $T_m - T_c$ was computed for each thermocouple in each test (Table 3). The final correction for each thermocouple (average of five values of $T_m - T_c$) is recorded in Table 3.

Table II.3

Thermocouple Number	Test No. 1: Average EMF, mV	Test No. 1: Average EMF + EMF corresp. to cold junctn. temperature	Test No. 1: Temperature from the thermocouple T_c	Test No. 1: Difference T_m-T_c	Test No. 2: Av, EMF	Test No. 2: AV EMF + C.J.	Test No. 2: T_c	Test No. 2: T_m-T_c	Test No. 3: Av. EMF	Test No. 3: Av. EMF + C.J.	Test No. 3: T_c	Test No. 3: T_m-T_c
1 (btm)	2.315	4.0778	99.490	0.9133	2.312	4.0742	99.404	1.00	2.311	4.074	99.399	1.005
2	2.303	4.0658	99.201	1.203	2.303	4.0652	99.187	1.217	2.303	4.066	99.206	1.198
3	2.347	4.1098	100.263	0.141	2.348	4.1102	100.273	0.131	2.342	4.105	100.147	0.257
4	2.3228	4.0856	99.679	0.725	2.323	4.0855	99.677	0.727	2.3157	4.079	99.512	0.892
5	2.350	4.1128	100.336	0.068	2.346	4.1082	100.224	0.180	2.343	4.106	100.171	0.233
6	2.315	4.0778	99.491	0.913	2.326	4.0879	99.734	0.670	2.313	4.076	99.443	0.961
7	2.357	4.1198	100.504	-0.100	2.357	4.1192	100.490	-0.086	2.355	4.118	100.461	-0.057
8	2.334	4.0968	99.949	0.455	2.335	4.0972	99.959	0.445	2.332	4.095	99.906	0.498
9	2.33125	4.0940	99.883	0.521	2.333	4.0952	99.911	0.493	2.331	4.094	99.884	0.520
10 (top)	2.361	4.1238	100.601	-0.197	2.360	4.1222	100.562	-0.158	2.361	4.124	100.606	-0.202
	T_m = 100.404, T_R = 43.82				T_m = 100.404, T_R = 43.805				T_m = 100.404, T_R = 43.825			

/continued

Table II.3 continued

Thermocouple number	Test No. 4				Test No. 5				Average Val. of $T_m - T_c$
	Av. EMF	Av. EMF + C.J.	T_c	$T_m - T_c$	Av. EMF	Av. EMF + C.J.	T_c	$T_m - T_c$	
1 (btm)	2.325	4.0836	99.630	0.873	2.3215	4.0801	99.546	0.906	0.94
2	2.324	4.0826	99.606	0.897	2.315	4.0776	99.486	0.967	1.08
3	2.366	4.1246	100.620	-0.117	2.356	4.1186	100.475	-0.022	0.08
4	2.341	4.0996	100.017	0.486	2.331	4.0936	99.872	0.581	0.68
5	2.366	4.1246	100.620	-0.117	2.356	4.1186	100.476	-0.023	0.07
6	2.336	4.0946	99.896	0.607	2.328	4.0906	99.799	0.654	0.76
7	2.375	4.1336	100.837	-0.334	2.363	4.1256	100.644	-0.191	-0.15
8	2.35	4.1086	100.234	0.269	2.337	4.0996	100.017	0.436	0.42
9	2.346	4.1046	100.137	0.366	2.341	4.1036	100.113	0.340	0.45
10 (top)	2.375	4.1336	100.837	-0.334	2.368	4.1306	100.765	-0.312	-0.24
	$T_m = 100.503\ ^oC$ $T_R = 43.715\ ^oC$				$T_m = 100.453\ ^oC$ $T_R = 43.815\ ^oC$				

Appendix III

Sample Calculation

Run No. 55 Date: 5.7.1977

III.1. Experimental readings

Steam temperature, T_s .. .. 147.8°C

Steam pressure, P_s .. .. 52 psig

Submergence, S 39%

Atmospheric pressure, P atm .. .. .. 759.8 mm Hg

Vapour condensate flow rate, W_g:

Volume collected .. .. 420 cm³

Time of collection .. .. 42.3 sec

Circulating liquid flow rate, W_L:

Time taken by the liquid to fill a height of 20 cm in the 3 in. dia. calibrated measuring cylinder .. .. 23.1 sec

Thermometer readings:

Bottom temperature .. .. 100.7°C

Top temperature .. .. 98.8°C

Cold junction temperature .. .. .. 43.7°C

Steam condensate flow rates, W_{si} (Table III.1.)

Table III.1

Compartment Number	1 Bottom	2	3	4	5	6	7	8	9 Top
Volume collected, cm³	1849	1907	1840	1950	1963	2098	2116	2158	2249

Time of collection for all compartments: 1667.3 sec.

Thermocouple readings (Table III.2).

Table III.2

Thermocouple number	1 (btm)	2	3	4	5	6	7	8	9	10 (top)
Average emf [mV]	2.403	2.431	2.433	2.441	2.427	2.403	2.416	2.418	2.418	2.375

III.2. Primary calculations

Liquid flow rate at the tube exit, W_L

The capacity of 20 cm height in the measuring cylinder is 1025.33 cm^3

$$W_L = \frac{1025.33 \quad (cm^3)}{23.1 \quad (sec)} \times 1 \ \frac{gr}{cm^3} = 44.387 \ \frac{gr}{sec} = 352.28 \ \frac{lb}{hr}$$

Vapour flow rate at the tube exit, W_g

$$W_g = \frac{420 \ (cm^3)}{42.3 (sec)} \times 1 \ \frac{gr}{cm^3} = 9.929 \ \frac{gr}{sec} = 78.8035 \ \frac{lb}{hr}$$

Total mass flow rate, W

$$W = W_L + W_g = 431.084 \quad (lb/hr)$$

Exit quality, x_{10}

$$x_{10} = \frac{W_g}{W_g + W_L} = 0.1828$$

Bulk fluid temperature distribution, T_i (i = 1, ..., 10)

The cold junction temperature is 43.7°C, which corresponds to an e.m.f. of 1.758 mV (see Appendix II, Section II.3.).

Table III.3

Thermo-couple number	Emf + 1.758 [mV]	Corresponding Temperature, [°C]	Calibration correction [°C]	Corrected Temperature, [°C]
1	4.1607	101.49	+0.94	102.43
2	4.1890	102.18	+1.08	103.26
3	4.1913	102.23	+0.08	102.31
4	4.1989	102.41	+0.68	103.09
5	4.1853	102.09	+0.07	102.16
6	4.1607	101.49	+0.76	102.25
7	4.1744	101.82	-0.15	101.67
8	4.1762	101.87	+0.42	102.29
9	4.1760	101.86	+0.45	102.31
10	4.1335	100.83	-0.24	100.59

III.3. Heat balance

The total heat transferred to the evaporating fluid, Q:

$$Q = W_g (H_{g10} - H_{L10}) + W(H_{L10} - H_{L1}) \qquad (3.3)$$

H_{L10}: enthalpy of liquid at the exit temperature, T_{10}

H_{L1}: enthalpy of liquid at the inlet temperature, T_1

$H_{g10} - H_{L10}$: latent heat of evaporation at the exit temperature.

H_{L10}, H_{L1} and $H_{Lg10} = H_{g10} - H_{L10}$ are calculated from equations I.1.4 and I.1.6 respectively (Appendix I) (the temperatures have been converted into ^{o}F).

$$H_{L10} = -33.6472 + 1.0085 \times 213.062 = 181.24 \quad [BTU/lb]$$

$$H_{L1} = -33.6472 + 1.0085 \times 216.374 = 184.58 \quad [BTU/lb]$$

$$H_{Lg10} = 1085.69 - 0.64074 \times 213.062 = 969.67 \quad [BTU/lb]$$

$$Q = 78.8035 \times 969.67 + 431.084 \; [181.24 - 184.58]$$

$$Q = 74973.57 \quad [BTU/hr]$$

III.4. Calculation of local quantities

Mean bulk fluid temperature in each compartment, T_{bi}

$$T_{bi} = \frac{T_i + T_{i+1}}{2}, \quad (i = 1, \ldots, 9)$$

Overall temperature driving force in each compartment, ΔT_{ovi}

$$\Delta T_{ovi} = T_s - T_{bi}$$

Values of T_{bi} and ΔT_{ovi} are in Table III.4.

Table III.4.

Compartment Number	T_{bi}, ^{o}C	T_{bi}, ^{o}F	ΔT_{ovi}, ^{o}F
1 bottom	102.84	217.11	80.93
2	102.78	217.00	81.04
3	102.70	216.86	81.18
4	102.62	216.72	81.32
5	102.21	215.98	82.06
6	101.96	215.53	82.51
7	101.98	215.56	82.47
8	102.30	216.14	81.90
9 top	101.45	214.61	83.43

Steam condensate flow rates, W_{si}

$$W_{si} = \frac{\text{Weight of steam condensate collected}}{\text{Time of collection}}$$

In order to minimise the error in W_{si}, the curve of W_{si} versus the axial co-ordinate Z/L (in which L is the total heated length of the tube and Z is the distance from the bottom of it) is smoothed as shown in Fig. III.1. The experimental and smoothed values of W_{si} are shown in Table III.5.

Table III.5.

Compartment number, i	W_{si} experimental, gr/sec	W_{si} smoothed, gr/sec	W_{si} smoothed lb/hr
1 bottom	1.10898	1.108	8.79379
2	1.14376	1.120	8.88903
3	1.10358	1.140	9.04777
4	1.16955	1.160	9.20650
5	1.17735	1.188	9.42873
6	1.25832	1.220	9.68270
7	1.26912	1.260	10.00016
8	1.29431	1.302	10.33350
9 top	1.34888	1.348	10.69859

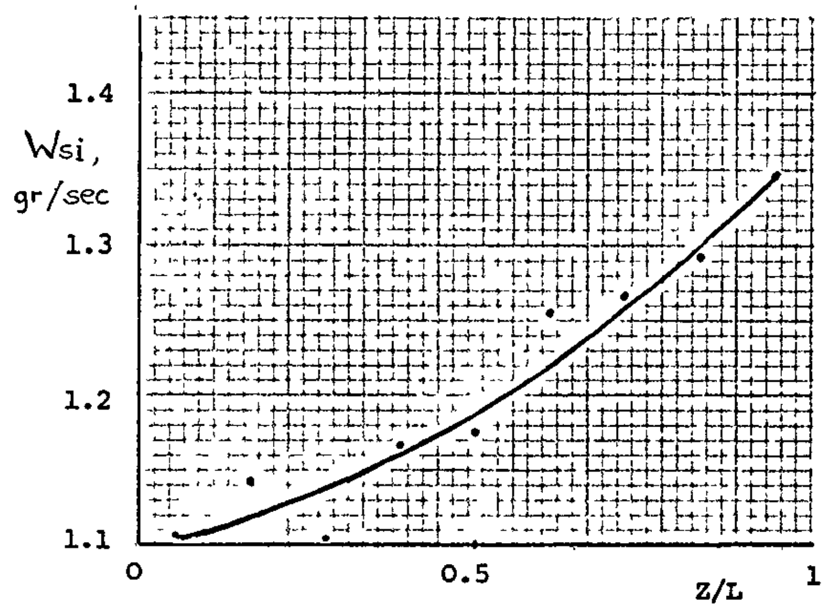

Fig. III.1

Local heat fluxes, q_i

The latent heat of evaporation of water at 147.8°C (298.04°F) is given by equation I.1.11.

$$H_{Lg} = 1121.06 - 0.70294 \times 298.04 = 911.6 \quad \text{BTU/lb.}$$

The first approximation to the heat added to each compartment of the tube, Q_i', is given by:

$$Q_i' = W_{si} H_{Lg} \qquad (i = 1, \ldots, 9)$$

The nine values of Q_i are shown in Table III.6. Their sum is:

$$Q' = 78471.16 \quad \text{BTU/hr.}$$

Due to heat losses to the surroundings, the values of Q_i' should be corrected according to equation (3.8):

$$Q_i = Q_i' \frac{Q}{Q'} = 0.95543\, Q_i'$$

where Q_i are the "true" heats added to the compartments i. The local heat fluxes are:

$$q_i = \frac{Q_i}{A_i} = \frac{Q_i}{0.15444 \text{ ft}^2}$$

Table III.6. records Q_i', Q_i and q_i for each compartment as well as the values of q_i given by the computer, $q_i(C)$.

Table III.6

Compartment number, i	Q_i', $\frac{BTU}{hr}$	Q_i, $\frac{BTU}{hr}$	q_i, $\frac{BTU}{hr\ ft^2}$	$q_i(C)$, $\frac{BTU}{hr\ ft^2}$
1 bottom	8016.43	7659.14	49593	49582
2	8103.21	7742.04	50129	50119
3	8247.97	7780.36	51025	51014
4	8392.64	8018.58	51920	51909
5	8595.20	8212.11	53173	53162
6	8826.75	8433.34	54606	54594
7	9116.09	8709.78	56396	56384
8	9420.02	9000.17	58276	58263
9 top	9752.84	9318.15	60335	60322

Local overall heat transfer coefficients, U_i

$$U_i = \frac{q_i}{\Delta T_{ovi}} \qquad \text{(see Table III.7.)}$$

where U_i is in [BTU/hr ft² °F]

Local film heat transfer coefficients for condensing steam, h_{si}

$$h_{si} = 3826 - 0.01\, q_i \qquad \text{(see Table III.7.)}$$

where h_{si} is in [BTU/hr ft² °F]

Thermal conductivity of the tube wall, k_{si}

$$k_{si} = 9.15 + 0.0066 \frac{T_s + T_{bi}}{2} \qquad \text{(see Table III.7.)}$$

where k_{si} is in [BTU/hr ft ^{o}F]

Local two phase heat transfer coefficients, h_{TPi}

$$h_{TPi} = \frac{1}{(1/U_i) - \frac{D_a \ln (D_e/D_a)}{k_{si}} - \frac{D_a}{h_s D_e}}$$

where D_e = outside diameter and D_a = inside diameter of the test section. After calculating the constants:

$$h_{TPi} = \frac{1}{\frac{1}{U_i} - \frac{0.00502}{k_{si}} - \frac{0.87095}{h_{si}}}$$

where h_{TPi} is in BTU/hr ft² ^{o}F.

The values of U_i, h_{si}, k_{si} and h_{TPi} are in Table III.7 in which the computer values of h_{TPi}(C) are also shown.

Table III.7

Compartment number, i	U_i	h_{si}	k_{si}	h_{TPi}	h_{TPi}(C)
1 bottom	612.79	3330.07	9.9771	1153.1	1153.0
2	618.57	3324.71	9.9769	1174.4	1174.3
3	628.54	3315.75	9.9766	1211.9	1211.4
4	638.46	3306.80	9.9763	1250.5	1250.1
5	647.98	3294.27	9.9750	1289.3	1288.4
6	661.81	3279.94	9.9742	1347.4	1346.7
7	683.83	3262.04	9.9743	1445.0	1445.1
8	711.55	3243.24	9.9753	1578.3	1578.7
9	723.18	3222.65	9.9725	1641.7	1640.8

Quality distribution along the tube, x_i

The exit quality is $x_{10} = 0.1828$. The quality of the two-phase mixture in the individual compartments is obtained from equation (3.12).

$$x_i = \frac{x_{i+1} H_{Lg\ i+1} + H_{L\ i+1} - H_{Li} - (Q_i/W)}{H_{Lgi}}$$

In order to use this equation, the following quantities need to be calculated:

a) Enthalpy of liquid H_{Li} at the inlet of each compartment, at temperature T_i. (Equation I.1.4.).

b) Latent heat of evaporation H_{Lgi} at the inlet of each compartment, at temperature T_i. (Equation I.1.6.).

c) Ratio of the local heat transferred to the fluid in compartment i to the total mass flow rate, Q_i/W.

Values of a), b) and c) are shown in Table III.8.

Table III.8

Compartment number, i	H_{Li}, $\frac{BTU}{lb}$	H_{Lgi}, $\frac{BTU}{lb}$	Q_i/W, $\frac{BTU}{lb}$
1 bottom	184.58	967.55	17.7672
2	186.09	966.59	17.9595
3	184.36	967.69	18.0484
4	185.78	966.79	18.6009
5	184.09	967.86	19.0499
6	184.25	967.76	19.5631
7	183.20	968.43	20.2044
8	184.33	967.71	20.8780
9 top	184.36	967.69	21.6156

The values of liquid enthalpy and latent heat at the exit of the top compartment are:

$$H_{L10} = 181.24 \quad [BTU/lb]$$

$$H_{Lg10} = 969.67 \quad [BTU/lb]$$

For $i = 9$

$$x_9 = \frac{x_{10} H_{Lg10} + H_{L10} - H_{L9} - (Q_9/W)}{H_{Lg9}}$$

$$x_9 = \frac{(0.1828)(969.67) + 181.24 - 184.36 - 21.6156}{967.69}$$

$$x_9 = 0.15761.$$

For $I = 8$

$$x_8 = \frac{(0.15761)(967.69) + 184.36 - 184.33 - 20.8780}{967.61}$$

$$x_8 = 0.13607$$

For $i = 7$

$$x_7 = \frac{(0.13607)(967.61) + 184.33 - .183.20 - 20.2044}{968.43}$$

$$x_7 = 0.11626$$

For $i = 6$

$$x_6 = \frac{(0.11626)(968.43) + 183.20 - 184.25 - 19.5631}{967.76}$$

$$x_6 = 0.09504$$

For $i = 5$

$$x_5 = \frac{(0.09504)(967.76) + 184.25 - 184.09 - 19.0499}{967.86}$$

$$x_5 = 0.07551$$

For $i = 4$

$$x_4 = \frac{(0.07551)(967.86) + 184.09 - 185.78 - 18.6009}{966.79}$$

$$x_4 = 0.05460$$

For $i = 3$

$$x_3 = \frac{(0.0546)(966.79) + 185.78 - 184.36 - 18.0484}{967.69}$$

$$x_3 = 0.03736$$

For $i = 2$

$$x_2 = \frac{(0.03736)(967.69) + 184.36 - 186.09 - 17.9595}{966.59}$$

$$x_2 = 0.01703$$

For $i = 1$

$$x_1 = \frac{(0.01703)(966.59) + 186.09 - 184.58 - 17.7672}{967.55}$$

$$x_1 = 0.00021$$

Mean quality in each compartment, x_{bi}

$$x_{bi} = \frac{x_i + x_{i+1}}{2} \qquad (i = 1, \ldots, 9)$$

Values of x_{bi} for the nine compartments are shown in Table III.9., together with the values given by the computer, $x_{bi}(C)$.

Table III.9

Compartment number, i	x_{bi}	x_{bi} (C)
1 bottom	0.00862	0.00841
2	0.02719	0.02698
3	0.04598	0.04588
4	0.06505	0.06507
5	0.08527	0.08529
6	0.10565	0.10566
7	0.12616	0.12615
8	0.14684	0.14682
9 top	0.17020	0.17021

Lockhart-Martinelli parameter, $(1/X_{tt})_i$

$$\frac{1}{X_{tt\ i}} = \left(\frac{x_{bi}}{1 - x_{bi}}\right)^{0.9} \left(\frac{\rho_{Li}}{\rho_{gi}}\right)^{0.5} \left(\frac{\mu_{gi}}{\mu_{Li}}\right)^{0.1}, \qquad (i = 1, \ldots, 9)$$

The physical properties are evaluated by means of equations I.1.2, I.1.3, I.1.7 and I.1.8 of Appendix I. For the bottom section (i = 1)

$$T_1 = 217.11^{\circ}\mathrm{F}.$$

$$\rho_{L1} = 65.432 - (0.02564)(217.11) = 59.686 \quad \mathrm{lb/ft^3}$$

$$\rho_{g1} = -0.12429 + (0.000762)(217.11) = 0.04113\ \mathrm{lb/ft^3}$$

$$\mu_{L1} = 1.5171 - (0.00397)(217.11) = 0.6552 \quad [\mathrm{lb/(ft\ hr)}]$$

$$\mu_{g1} = 0.01944 + (4.583 \times 10^{-5})(217.11) = 0.02939\ [\mathrm{lb/(ft\ hr)}]$$

$$x_{b1} = 0.00862$$

$$\left(\frac{x_{b1}}{1 - x_{b1}}\right)^{0.9} = 0.01397$$

$$\left(\frac{\rho_{L1}}{\rho_{g1}}\right)^{0.5} = 38.094$$

$$\left(\frac{\mu_{g1}}{\mu_{L1}}\right)^{0.1} = 0.73313$$

$$\left(\frac{1}{X_{tt}}\right)_1 = 0.39015$$

The values of $(1/X_{tt})_i$ for all compartments can be found in Table III.10.

Local film temperature difference, ΔT_{fi}

$$\Delta T_{fi} = q_i/h_{TPi}, \quad {}^{\circ}F.$$

Dimensionless reciprocal of the film temperature difference, $T_{bi}/\Delta T_{fi}$

The mean temperature of the fluid in each compartment is converted into the absolute scale in $^{\circ}R$. Then the values of $T_{bi}/\Delta T_{fi}$ are calculated and tabulated in Table III.10.

Table III.10

Compartment number, i	$\left(\frac{1}{X_{tt}}\right)_i$	$\left(\frac{1}{X_{tt}}\right)_i$ (C)	ΔT_{fi}	$\frac{T_{bi}}{\Delta T_{fi}}$	$\frac{T_{bi}}{\Delta T_{fi}}$ (C)
1 bottom	0.39015	0.382	43.01	15.74	15.75
2	1.11729	1.109	42.68	15.86	15.86
3	1.82682	1.823	42.10	16.08	16.07
4	2.54536	2.546	41.52	16.30	16.30
5	3.33362	3.335	41.24	16.39	16.38
6	4.14224	4.143	40.53	16.67	16.66
7	4.96033	4.959	39.03	17.31	17.31
8	5.78052	5.778	36.92	18.31	18.32
9 top	6.86314	6.863	36.75	18.36	18.35

Local liquid phase heat transfer coefficients, h_{Li}

$$h_{Li} = 0.023 \left(\frac{k_{Li}}{D}\right) Re_{Li}^{0.8} \; Pr_{Li}^{0.4}$$

Reynolds number: $Re_{Li} = \dfrac{4W(1 - x_{bi})}{\pi D \mu_{Li}}$

Prandtl number: It is calculated from equation I.1.10.

Thermal conductivity of liquid, k_{Li}. It is calculated from equation I.1.9.

The values of $Re_{Li}^{0.8}$, $Pr_{Li}^{0.4}$, k_{Li} and k_{Li} can be seen in Table III.11, together with the computer-calculated values of the liquid phase heat transfer coefficient, $h_{Li}(C)$.

Table III.11

Compartment Number, i	Re_{Li}	Pr_{Li}	k_{Li}, $\frac{BTU}{hr\ ft\ ^{o}F}$	h_{Li}, $\frac{BTU}{hr\ ft^2\ ^{o}F}$	$h_{Li}(C)$, $\frac{BTU}{hr\ ft^2\ ^{o}F}$
1	11429.9	1.6781	0.39378	270.4	270.5
2	11208.4	1.6793	0.39377	266.3	266.3
3	10982.4	1.6808	0.39376	262.1	262.1
4	10753.4	1.6823	0.39375	257.8	257.8
5	10474.1	1.6901	0.39367	252.8	252.8
6	10202.7	1.6948	0.39363	247.8	248.0
7	9981.1	1.6944	0.39363	243.5	243.5
8	9778.7	1.6884	0.39369	239.2	239.2
9	9424.2	1.7045	0.39353	233.0	233.0

Ratio of two phase heat transfer coefficient to liquid phase heat transfer coefficient

Values of h_{TP}/h_L are given in Table III.12 for each compartment.

Homogeneous Froude number, Fr_i

$$Fr_i = \frac{1}{gD}\left(\frac{W^2}{A_o^{\,2}}\right)\left(\frac{x_{bi}}{\rho_{gi}} + \frac{(1 - x_{bi})}{\rho_{Li}}\right)^2$$

$g = 32.16 \text{ ft/sec}^2 = 416793600 \text{ ft/hr}^2$

$D = 0.07266 \text{ ft}$

$W = 431.084 \text{ lb/hr}$

$A_o = 0.004146 \text{ ft}^2$

$$F_{ri} = 356.984\left(\frac{x_{bi}}{\rho_{gi}} + \frac{(1 - x_{bi})}{\rho_{Li}}\right)^2$$

The following table gives the values of density and quality for the different compartments along the test section.

Compartment number, i	x_{bi}	ρ_{Li}, lb/ft^3	ρ_{gi}, lb/ft^3	$\frac{x_{bi}}{\rho_{gi}}$	$\frac{1 - x_{bi}}{\rho_{Li}}$
1 bottom	.00862	59.6860	.04113	.20958	.016610
2	.02719	59.6887	.041052	.66233	.016298
3	.04598	59.6923	.04094	1.12310	.015982
4	.06505	59.6961	.04083	1.59319	.015661
5	.08527	59.715	.04027	2.11746	.015318
6	.10565	59.7265	.03993	2.64588	.014974
7	.12616	59.7256	.03995	3.15755	.014631
8	.14684	59.7108	.04039	3.63555	.014288
9 top	.17020	59.7500	.03923	4.33851	.013888

Values of Fr_i for the nine compartments are given in Table III.12

Liquid phase Froude number, Fr_{Li}

$$Fr_{Li} = \frac{1}{gD}\left(\frac{W^2}{A_o^{\,2}}\right)\frac{(1 - x_{bi})^2}{\rho_{Li}^{\,2}} = 356.984\left(\frac{1 - x_{bi}}{\rho_{Li}}\right)^2$$

Values of Fr_{Li} for the nine compartments are given in Table III.12.

Vapour phase Froude number, Fr_{gi}

$$Fr_{gi} = \frac{1}{gD}\left(\frac{W^2}{A_o^{\,2}}\right)\left(\frac{x_{bi}}{\rho_{gi}}\right)^2 = 356.984\left(\frac{x_{bi}}{\rho_{gi}}\right)^2$$

Values of Fr_{gi} for the nine compartments are given in Table III.12.

Table III.12

		Homogeneous		Liquid		Vapour	
i	$(h_{TP}/h_L)_i$	Fr_i	Fr_i (C)	Fr_{Li}	Fr_{Li} (C)	Fr_{gi}	Fr_{gi} (C)
1	4.264	18.26	17.4	0.098	.098	15.7	14.9
2	4.410	164.40	161.8	0.095	.095	156.6	154.0
3	4.624	463.19	460.8	0.091	.091	450.3	448.0
4	4.851	924.01	923.5	0.088	.088	906.1	905.6
5	5.100	1623.82	1623.82	0.084	.084	1600.6	1600.4
6	5.437	2527.50	2526.2	0.080	.080	2499.1	2497.8
7	5.934	3592.23	3584.8	0.076	.076	3559.1	3551.8
8	6.598	4755.5	4744.3	0.073	.073	4718.3	4707.2
9	7.046	6762.5	6758.1	0.069	.069	6719.4	6715.0

III.5. Calculation of the length-mean quantities

Average bulk fluid temperature, $\overline{T}_b$

$\overline{T}_b$ is calculated, as explained in section 3.3.4., by means of the equation:

$$\bar{T}_b = \left(\sum_{i=1}^{9} T_i + \sum_{i=1}^{9} T_{i+1}\right)/18 = \sum_{i=1}^{9} T_{bi}/9$$

$$\bar{T}_b = 102.32^{\circ}C = 216.176^{\circ}F.$$

Average quality, $\bar{x}$

$$\bar{x} = \left(\sum_{i=1}^{9} x_i + \sum_{i=1}^{9} x_{i+1}\right)/18 = \sum_{i=1}^{9} T_{bi}/9$$

$$\bar{x} = 0.08677.$$

Overall temperature driving force, $\Delta\bar{T}_{ov}$

$$\Delta\bar{T}_{ov} = T_s - \bar{T}_b = 147.8 - 102.32^{\circ}C = 45.48^{\circ}C = 81.86^{\circ}F$$

Length-mean heat flux, $\bar{q}$

$$\bar{q} = \frac{Q}{A} = \frac{74973.57 \text{ BTU/hr}}{1.39 \quad \text{ft}^2} = 53938 \frac{\text{BTU}}{\text{hr ft}^2}$$

Computer value: 53928 BTU/(hr ft²)

Length mean overall heat transfer coefficient, $\bar{U}$

$$\bar{U} = \frac{\bar{q}}{\Delta\bar{T}_{ov}} = \frac{53938}{81.86} = 658.905 \frac{\text{BTU}}{\text{hr ft}^2\,{}^{\circ}\text{F}}$$

Film heat transfer coefficient for condensing steam, $\bar{h}_s$

$$\bar{h}_s = 3826 - 0.01\,\bar{q} = 3286.62 \frac{\text{BTU}}{\text{hr ft}^2\,{}^{\circ}\text{F}}$$

<u>Thermal conductivity of the test section material, $\bar{k}_s$</u>

$$\bar{k}_s = 9.15 + 0.0066 \frac{(T_s + \bar{T}_b)}{2} = 9.9753 \frac{\text{BTU}}{\text{hr ft}^\circ\text{F}}$$

<u>Length-mean two-phase heat transfer coefficient, $\bar{h}_{TP}$</u>

$$\bar{h}_{TP} = \frac{1}{\frac{1}{\bar{U}} - \frac{0.00502}{\bar{k}_s} - \frac{0.87095}{\bar{h}_s}}$$

$$\bar{h}_{TP} = \frac{1}{\frac{1}{658.905} - \frac{0.00502}{9.9753} - \frac{0.87095}{3286.62}} = 1334.35 \frac{\text{BTU}}{\text{hr ft}^2\,^\circ\text{F}}$$

The computer value of $\bar{h}_{TP}$ is 1333.7 $\frac{\text{BTU}}{\text{hr ft}^2\,^\circ\text{F}}$

<u>Liquid-phase heat transfer coefficient, $\bar{h}_L$</u>

$$\bar{h}_L = 0.023 \frac{k_L}{D} \left(\frac{4W(1-\bar{x})}{\pi D \mu_L}\right)^{0.8} \left(\frac{C_p \mu_L}{k_L}\right)^{0.4}$$

$D = 0.07266$ ft

$k_L = 0.3717 + 0.0001015\ \bar{T}_b, \frac{\text{BTU}}{\text{hr ft}^\circ\text{F}}$, after equation I.1.9., Appendix I.

$$k_L = 0.3937 \frac{\text{BTU}}{\text{hr ft}^\circ\text{F}}$$

$(1 - \bar{x}) = 0.9132$

$W = 431.084$ lb/hr

$\mu_L = 1.5171 - 0.00397\ \bar{T}_b$ (after equation I.1.7.)

$\mu_L = 0.65892 \frac{\text{lb}}{\text{ft hr}}$

$$\frac{4W(1-\bar{x})}{\pi D \mu_L} = 10469.11 = Re_L$$

$$Re_L^{0.8} = 1644.1$$

$$Pr_L = \frac{Cp\mu_L}{k_L} = 3.965 - 0.01053\ \overline{T}_b \quad \text{(after equation I.1.10).}$$

$$Pr_L = 1.688; \quad Pr_L^{0.4} = 1.23296$$

$$\bar{h}_L = 252.6\ \frac{BTU}{hr\ ft^2\ {}^oF}$$

Computer value of $\bar{h}_L = 252.6\ \frac{BTU}{hr\ ft^2\ {}^oF}$

<u>Heat transfer ratio, $\bar{h}_{TP}/\bar{h}_L$</u>

$$\frac{\bar{h}_{TP}}{\bar{h}_L} = \frac{1334.35}{252.6} = 5.282$$

<u>Lockhart-Martinelli parameter, $1/X_{tt}$</u>

$$\frac{1}{X_{tt}} = \left(\frac{\bar{x}}{1-\bar{x}}\right)^{0.9} \left(\frac{\rho_L}{\rho_g}\right)^{0.5} \left(\frac{\mu_g}{\mu_L}\right)^{0.1}$$

$$\left(\frac{\bar{x}}{1-\bar{x}}\right)^{0.9} = \left(\frac{0.08677}{1-0.08677}\right)^{0.9} = 0.12023$$

$$\rho_L = 65.432 - (0.02564)\ \overline{T}_b = 59.71\ \text{lb/ft}^3$$

$$\rho_g = 0.12429 + (0.000762)\ \overline{T}_b = 0.04042\ \text{lb/ft}^3$$

$$\mu_L = 1.5171 - (0.00397)\ \overline{T}_b = 0.65892\ \text{lb/(ft hr)}$$

$$\mu_g = 0.01944 + (4.583 \times 10^{-5})\ \overline{T}_b = 0.02935\ \text{lb/(ft hr)}$$

$$\left(\frac{\rho_L}{\rho_g}\right)^{0.5} = 38.43$$

$$\left(\frac{\mu_g}{\mu_L}\right)^{0.1} = 0.732617$$

$$\frac{1}{X_{tt}} = 3.385$$

(Computer value = 3.387)

<u>Film temperature difference, $\overline{\Delta T}_f$</u>

$$\overline{\Delta T}_f = \frac{\bar{q}}{h_{TP}} = \frac{53938}{1334.35} = 40.42^{o}F$$

<u>Dimensionless reciprocal of the film temperature difference, $\bar{T}_b/\Delta T_f$</u>

$$\bar{T}_b = 216.176^{o}F = 676.176^{o}R$$

$$\frac{\bar{T}_b}{\overline{\Delta T}_f} = \frac{676.176}{40.42} = 16.73$$

(Computer value = 16.71)

<u>Homogeneous Froude number, $\overline{Fr}$</u>

$$\overline{Fr} = \frac{1}{g_D}\left(\frac{W}{A_o}\right)^2 \left(\frac{\bar{x}}{\rho_g} + \frac{(1-\bar{x})}{\rho_L}\right)^2$$

$$= 356.984\left(\frac{\bar{x}}{\rho_g} + \frac{(1-\bar{x})}{\rho_L}\right)^2$$

$$\left(\frac{\bar{x}}{\rho_g} + \frac{1-\bar{x}}{\rho_L}^2\right) = \left(\frac{0.08677}{0.04042} + \frac{0.9132}{59.71}\right)^2 =$$

$$\overline{Fr} = 1668.62$$

(Computer value = 1672.2)

<u>Liquid phase Froude number, $\overline{Fr}_L$</u>

$$\overline{Fr}_L = \frac{1}{g_D}\left(\frac{W}{A_o}\right)^2 \left(\frac{1-\bar{x}}{\rho_L}\right)^2 = 0.0834$$

(Computer value = 0.083)

<u>Vapour phase Froude number, $\overline{Fr}_g$</u>

$$\overline{Fr}_g = \frac{1}{g_D}\left(\frac{W}{A_o}\right)^2\left(\frac{\bar{x}}{\rho_g}\right)^2 = 1645.111$$

(Computer value = 1648.7)

Appendix IV

Correlation Technique

The method of linear regression with several variables described in reference V1 was used in the correlation of two-phase heat transfer coefficients.

The regression formulas are not restricted to variables having a dependent-independent relationship, but merely describe in mathematical terms the nature of the relation betwêen the variables.

Correlations of the form:

$$Y = A\, X_1^{\,b_1}\; X_2^{\,b_2}\; \ldots\ldots\; X_n^{\,b_n} \qquad \text{(IV.1)}$$

will be considered, where Y is a dimensionless form of the two phase heat transfer coefficient and X_1, X_2, ..., X_n are dimensionless "independent" variables. Taking logarithms of equation IV.1:

$$\ell n\, Y = \ell n\, A + b_1\, \ell n\, X_1 + b_2\, \ell n\, X_2 + \ldots\ldots + bu\, \ell n\, X_n \qquad \text{(IV.2)}$$

Defining:

$$a = \ell n\, A$$
$$y = \ell n\, Y$$
$$x_1 = \ell n\, X_1$$
$$x_2 = \ell n\, X_2$$
$$\vdots$$
$$x_m = \ell n\, X_n$$

$$y = a + b_1\, x_1 + b_2\, x_2 + \ldots\ldots\; b_n\, x_n \qquad \text{(IV.3)}$$

a, b_1, b_2, ... b_n are the regression coefficients which are determined from experimental values of y, x_1, x_2, ... x_n. Once these coefficients have been determined, predicted values of y can be calculated, and these will be denoted as $\hat{y}$. The correlating equation will have the form:

$$\hat{y} = a + b_1 x_1 + b_2 x_2 + \ldots\ldots + b_n x_n \qquad \text{(IV.4)}$$

The degree of fit of a multiple linear regression can be measured by the sum of squares of deviation of the experimental values of y from the predicted values, $\hat{y}$:

$$S = \sum_{i=1}^{N} (y_i - \hat{y}_i)^2 \qquad \text{(IV.5)}$$

where N is the number of data points used in the determination of the regression coefficients. Alternatively, equation IV.5 can be written as:

$$S = \sum_{i=1}^{N} (y_i - a - b_1 x_{1i} - b_2 x_{2i} - \ldots\ldots - b_n x_{ni})^2$$

In order to obtain the coefficients, S must be minimized. S is differentiated with respect to each of the constants and each derivative is equated to zero. For the particular case of three independent variables:

$$\frac{\partial S}{\partial a} = -2 \sum_{i=1}^{N} (y_i - a - b_1 x_{1i} - b_2 x_{2i} - b_3 x_{3i}) = 0$$

$$\sum_{i=1}^{N} y_i = Na + b_1 \sum_{i=1}^{N} x_{1i} + b_2 \sum_{i=1}^{N} x_{2i} + b_3 \sum_{i=1}^{N} x_{3i} \qquad \text{(IV.6)}$$

$$\frac{\partial S}{\partial b_1} = 2\sum_{i=1}^{N}\left[(y_i - a - b_1x_{1i} - b_2x_{2i} - b_3x_{3i})(-x_{1i})\right] = 0$$

$$\sum_{i=1}^{N} x_{1i}y_i = a\sum_{i=1}^{N} x_{1i} + b_1\sum_{i=1}^{N} x_{1i}^2 + b_2\sum_{i=1}^{N} x_{1i}x_{2i} + b_3\sum_{i=1}^{N} x_{1i}x_{3i} \quad \text{(IV.7)}$$

Similarly:

$$\sum_{i=1}^{N} x_{2i}y_i = a\sum_{i=1}^{N} x_{2i} + b_1\sum_{i=1}^{N} x_{2i}x_{1i} + b_2\sum_{i=1}^{N} x_{2i}^2 + b_3\sum_{i=1}^{N} x_{2i}x_{3i} \quad \text{(IV.8)}$$

$$\sum_{i=1}^{N} x_{3i}y_i = a\sum_{i=1}^{N} x_{3i} + b_1\sum_{i=1}^{N} x_{3i}x_{1i} + b_2\sum_{i=1}^{N} x_{3i}x_{2i} + b_3\sum_{i=1}^{N} x_{3i}^2 \quad \text{(IV.9)}$$

From IV.6

$$a = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2 - b_3\bar{x}_3 \quad \text{(IV.10)}$$

where $\bar{y}$, $\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$ are the average values of the form variables and are given by:

$$\bar{y} = \frac{\sum_{i=1}^{N} y_i}{N},\ \bar{x}_1 = \frac{\sum_{i=1}^{N} x_{1i}}{N},\ \bar{x}_2 = \frac{\sum_{i=1}^{N} x_{2i}}{N},\ \bar{x}_3 = \frac{\sum_{i=1}^{N} x_{3i}}{N} \quad \text{(IV.11)}$$

The constants a, b_1, b_2 and b_3 can be obtained by solving the system of equations IV.7 to IV.10.

If equation IV.10 is combined with equations IV.7, IV.8 and IV.9, the constant a is eliminated and the following equations are obtained:

$$b_1\sum_{i=1}^{N}(x_{1i}-\bar{x}_1)^2 + b_2\sum_{i=1}^{N}(x_{1i}-\bar{x}_1)(x_{2i}-\bar{x}_2) + b_3\sum_{i=1}^{N}(x_{2i}-\bar{x}_2)(x_{3i}-\bar{x}_3) =$$

$$= \sum_{i=1}^{N}(x_{2i}-\bar{x}_2)(y_i-\bar{y}) \quad \text{(IV.12)}$$

$$b_1 \sum_{i=1}^{N} (x_{2i}-\bar{x}_2)(x_{1i}-\bar{x}_1) + b_2 \sum_{i=1}^{N} (x_{2i}-\bar{x}_2)^2 + b_3 \sum_{i=1}^{N} (x_{2i}-\bar{x}_2)(x_{3i}-\bar{x}_3) =$$

$$= \sum_{i=1}^{N} (x_{2i}-\bar{x}_2)(y_i-\bar{y}) \qquad \text{(IV.13)}$$

$$b_1 \sum_{i=1}^{N} (x_{3i}-\bar{x}_3)(x_{1i}-\bar{x}_1) + b_2 \sum_{i=1}^{N} (x_{3i}-\bar{x}_3)(x_{2i}-\bar{x}_2) + b_3 \sum_{i=1}^{N} (x_{3i}-\bar{x}_3)^2$$

$$= \sum_{i=1}^{N} (x_{3i}-\bar{x}_3)(y_i-\bar{y}) \qquad \text{(IV.14)}$$

where

$$\sum_{i=1}^{N} (x_{1i}-\bar{x}_1)^2 = \sum_{i=1}^{N} x_{1i}^2 - \bar{x}_1 \sum_{i=1}^{N} x_{1i} = \text{SQX1}$$

$$\sum_{i=1}^{N} (x_{2i}-\bar{x}_2)^2 = \sum_{i=1}^{N} x_{2i}^2 - \bar{x}_2 \sum_{i=1}^{N} x_{2i} = \boxed{\text{SQX2}}$$

$$\sum_{i=1}^{N} (x_{3i}-\bar{x}_3)^2 = \sum_{i=1}^{N} x_{3i}^2 - \bar{x}_3 \sum_{i=1}^{N} x_{3i} = \text{SQX3}$$

$$\sum_{i=1}^{N} (x_{1i}-\bar{x}_1)(y_i-\bar{y}) = \sum_{i=1}^{N} x_{1i}y_i - \bar{y} \sum_{i=1}^{N} x_{1i} = \text{QYX1}$$

$$\sum_{i=1}^{N} (x_{2i}-\bar{x}_2)(y_i-\bar{y}) = \sum_{i=1}^{N} x_{2i}y_i - \bar{y} \sum_{i=1}^{N} x_{2i} = \text{QYX2}$$

$$\sum_{i=1}^{N} (x_{3i}-\bar{x}_3)(y_i-\bar{y}) = \sum_{i=1}^{N} x_{3i}y_i - \bar{y} \sum_{i=1}^{N} x_{3i} = \text{QYX3}$$

$$\sum_{i=1}^{N} (x_{1i}-\bar{x}_1)(x_{2i}-\bar{x}_2) = \sum_{i=1}^{N} x_{1i}x_{2i} - \bar{x}_1 \sum_{i=1}^{N} x_{2i} = Q12$$

$$\sum_{i=1}^{N} (x_{1i}-\bar{x}_1)(x_{3i}-\bar{x}_3) = \sum_{i=1}^{N} x_{1i}x_{3i} - \bar{x}_1 \sum_{i=1}^{N} x_{3i} = Q13$$

$$\sum_{i=1}^{N} (x_{2i}-\bar{x}_2)(x_{3i}-\bar{x}_3) = \sum_{i=1}^{N} x_{2i}x_{3i} - \bar{x}_2 \sum_{i=1}^{N} x_{3i} = Q23$$

The system of equations IV.11 - IV.14 is solved for b_1, b_2 and b_3, giving the equations:

$$b_1 = \frac{QYX1[SQX2 \times SQX3 - (Q23)^2]}{D} + \frac{QYX2[Q23 \times Q13 - Q12 \times SQX3]}{D} + \frac{QYX3[Q12 \times Q23 - Q13 \times SQX2]}{D} \tag{IV.15}$$

$$b_2 = \frac{QYX1[Q13 \times Q23 - Q12 \times SQX3]}{D} + \frac{QYX2[SQX1 \times SQX3 - (Q13)^2]}{D} + \frac{QYX3[Q12 \times Q13 - Q23 \times SQX1]}{D} \tag{IV.16}$$

$$b_3 = \frac{QYX1[Q12 \times Q23 - Q13 \times SQX2]}{D} + \frac{QYX2[Q13 \times Q12 - Q23 \times SQX1]}{D} + \frac{QYX3[SQX1 \times SQX2 - (Q12)^2]}{D} \tag{IV.17}$$

where:

$$D = SQX1 \times SQX2 \times SQX3 + 2 \times Q12 \times Q23 \times Q13 - SQX1(Q23)^2 - SQX2(Q13)^2 - SQX3(Q12)^2 \tag{IV.18}$$

$$a = \bar{y} - b_1\bar{x}_1 = b_2\bar{x}_2 - b_3\bar{x}_3 \tag{IV.19}$$

The use of these equations is illustrated with an example:

Example: The local two-phase heat transfer coefficients were correlated with 3 variables by a relationship of the form:

$$\frac{h_{TP}}{h_L} = f\left(\frac{1}{X_{tt}}, \frac{T_b}{\Delta T_f}, Fr_L\right)$$

A total of 473 data points were considered. For eachof the data points:

$$y_i = \ln\left(\frac{h_{TP}}{h_L}\right)_i \qquad i = 1, \ldots, 473$$

$$x_{1i} = \ln\left(\frac{1}{X_{tt}}\right)_i \qquad i = 1, \ldots, 473$$

$$x_{2i} = \ln\left(\frac{T_b}{\Delta T_f}\right)_i \qquad i = 1, \ldots, 473$$

$$x_{3i} = \ln Fr_{Li} \qquad i = 1, \ldots, 473$$

The following parameters of the data were determined:

a) Sum:

$$\sum_{i=1}^{473} y_i = 675.43612$$

$$\sum_{i=1}^{473} x_{1i} = 414.87699$$

$$\sum_{i=1}^{473} x_{2i} = 1447.10981$$

$$\sum_{i=1}^{473} x_{3i} = -700.76646$$

b) Average:

$$\bar{y} = 1.42798$$

$$\bar{x}_1 = 0.877118$$

$$\bar{x}_2 = 3.059428$$

$$\bar{x}_3 = =1.481535$$

c) Sum of squares:

$$\sum_{i=1}^{473} x_{1i}^2 = 578.09867$$

$$\sum_{i=1}^{473} x_{2i}^2 = 4459.07187$$

$$\sum_{i=1}^{473} x_{3i}^2 = 1659.95373$$

d) Sum of products

$$\sum_{i=1}^{473} x_{1i}y_i = 713.61969$$

$$\sum_{i=1}^{473} x_{2i}y_i = 2032.34540$$

$$\sum_{i=1}^{473} x_{3i}y_i = -1206.95847$$

$$\sum_{i=1}^{473} x_{1i}x_{2i} = 1219.31539$$

$$\sum_{i=1}^{473} x_{2i}x_{3i} = -2037.19084$$

$$\sum_{i=1}^{473} x_{1i}x_{3i} = -920.80568$$

With these results, the parameters in equations IV.15 to IV.18 can be calculated:

SQX1 = 214.2026

SQX2 = 31.7436

SQX3 = 621.7437

QYX1 = 121.1823

QYX2 = -34.1033

QYX3 = -206.2756

Q12 = -49.9712

Q23 = 106.7542

Q13 = -306.1505

The correlating equation will have the form:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3$$

Using equations IV.15 to IV.19 with the values of the parameters already determined, the following constants are obtained:

b_1 = 0.30749

b_2 = 0.03850

b_3 = 0.18697

a = 0.763475

The correlation is therefore written as:

$$\ell n\left(\frac{h_{TP}}{h_L}\right) = 0.763475 + 0.30749\ \ell n\left(\frac{1}{X_{tt}}\right) + 0.0385\ \ell n\left(\frac{T_b}{\Delta T_f}\right) -$$

$$- 0.18697\ \ell n\ Fr_L$$

or

$$\frac{h_{TP}}{h_L} = 2.146\left(\frac{1}{X_{tt}}\right)^{0.3075}\left(\frac{T_b}{\Delta T_f}\right)^{0.0385} Fr_L^{-0.187} \qquad \text{(IV.20)}$$