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RESEARCH ESTABLISHMENT

LUCAS HEIGHTS RESEARCH LABORATORIES

ADAPTATION OF A FREON-12 CRITICAL HEAT FLUX CORRELATION TO CORRELATE WATER DATA FROM UNIFORMLY HEATED VERTICAL TUBES

PART 1 : BASED ON CRITICAL HEAT FLUX DATA FOR WATER AT PRESSURES OF 3 TO 14 MPa

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ABSTRACT

Comparisons have been made between experimental critical heat flux (CHF) data for upflow of water in uniformly heated vertical tubes and values calculated from an empirical CHF correlation developed from Freon-12 data. When this correlation is re-evaluated to account for vapour Prandtl number effects, very good agreement is obtained between experimental data and calculated values over a wide range of coolant conditions.

Comparison of values calculated from the revised correlation with 2063 sets of CHF data obtained from experiments with water in vertical, uniformly

(Continued)

heated tubes shows a mean ratio of the calculated to experimental CHF of 0.82 and an r.m.s error of 5.8 per cent for the following coolant conditions:

(1) local pressure of 3.4 to 12 MPa,

(2) mass flux greater than approx. 300 kg s^{-1} m^{-2}, and

(3) thermal equilibrium value of exit quality greater than 0.1.

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CRITICAL HEAT FLUX; CORRELATIONS; FREONS; WATER; TUBES; MEDIUM PRESSURE; HIGH PRESSURE; EXPERIMENTAL DATA; LIQUID FLOW; PRANDTL NUMBER; COOLANTS

CONTENTS

(Continued)

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1. INTRODUCTION

The heat transfer characteristics associated with a change from pre-dryout to post-dryout conditions during a power transient have been investigated by the AAEC Research Establishment at the Lucas Heights Research Laboratories [Green 1978; Green and Lawther 1979, 1980]. These investigations used a vertical round tube test section, electrically heated and internally cooled by Freon-12 flowing at relatively low mass fluxes. Heat transfer characteristics were determined by calculating wall temperature responses as a function of time and comparing these with the corresponding temperature traces in the experiments. The main objectives of this work were to investigate post-dryout heat transfer characteristics and to develop suitable correlations for post-dryout heat transfer. Calculated temperatures were found to be very dependent on the onset of dryout conditions and available critical heat flux (CHF) correlations were insufficiently precise to enable the temperature responses to be predicted reliably [Green 1981a].

Ancillary work was commenced to obtain more accurate CHF data for the coolant conditions being investigated and to develop a general Freon-12 CHF correlation. Work on the latter objective [Green 1981b] proved most encouraging, a correlation being formulated which enabled the CHF for Freon-12 to be calculated for a wide range of coolant conditions. However, the data examined covered only a small range of Prandtl numbers, and had limited information relating to (a) short tubes and (b) low mass fluxes.

To investigate the generality of the correlation with a view to extending it to cover a wide range of conditions, a comparison was made with published CHF data for water in uniformly heated tubes.

2. PROPOSED FREON-12 CORRELATION

The general correlation proposed by Green [1981b] is

$$\frac{\phi D}{\mu_v \lambda} = \frac{1}{17000} Re_v^n \left(\frac{\rho_\ell}{\rho_v}\right)^m Pr_v^q \left(\frac{\sigma}{\rho_v \lambda D}\right)^p \quad f(L_s/D)\ (1+\delta)\ (1-\delta_1)$$

where $n = 1 - e^{-0.0067\ L_s/D}$

$$m = 0.1 + e^{-0.007\ L_s/D}$$

$$p = -0.5\ (0.15 + e^{-0.007(L_s/D)})$$

$$q = -m$$

$$f(L_s/D) = e^{4.25\ e^{-0.00366\ L_s/D}}$$

$(1+\delta)$ is a modifying factor to account for short tube effects, and δ is given by

$$\delta = e^{-0.14 * 10^8\ \sigma_N}\ e^{-0.02\ L/D}\quad ,$$

$(1-\delta_1)$ is a modifying factor to account for low mass flux effects, and δ_1 is given by

$$\delta_1 = 0.75\ e^{-BL/D\ \frac{G\sigma}{\rho_\ell \mu_\ell \lambda}}$$

$$B = 130.5\ e^{5.0\ e^{-0.02\,L/D}}$$

and where other symbols are defined in Section 8.

The correlation was found, in general, to compare favourably with experimental Freon-12 data, except for data in which the coolant exit quality was less than 10 per cent. With this exception, agreement was within ± 10 per cent for dimensionless saturation lengths (L_s/D) up to 150, and within ± 5 per cent for all other values of L_s/D.

3. RECONSIDERATION OF CORRELATION PARAMETERS AND FACTORS AS A RESULT OF EXAMINING EXPERIMENTAL CHF DATA FOR WATER

3.1 General

Although many experimental CHF data for Freon-12 were examined by Green [1981b], the range of vapour Prandtl numbers investigated was only 0.9 to 1.02, a great majority of them being at 0.95. Evaluation of the vapour Prandtl number index was therefore difficult, and hence some water data [Lee 1965] were examined first to verify the assumption that this index could be approximated by -m.

Furthermore, the short tube effect had been determined from data obtained over a limited range of coolant pressures, and the low flow effect determined from data obtained over a wide range of flow rates (down to 200 kg s^{-1} m^{-2}) but only in the pressure range 0.5 to 1.0 MPa. Nevertheless, these data provided reasonable ranges of values in all dimensionless groups, except vapour and liquid Prandtl numbers.

When examining extensive CHF data for another fluid such as water, the following considerations had, therefore, to be borne in mind:

(1) The vapour Prandtl number index might require re-evaluation.

(2) If the modifying components proved to be unsuitable, any re-evaluation should be based on the addition of only a vapour or liquid Prandtl number in the modifying factors (since these were the only dimensionless groups which had not significantly varied for Freon-12).

For these reasons, experimental CHF data for water were examined in the following sequence:

1. Long tubes, for which data did not involve low mass fluxes or low exit qualities. (This would enable the influence of vapour Prandtl number to be considered independently of other factors.)

2. Short tubes, for which low mass flux and low quality data were excluded, thus isolating short tube effects and enabling the validity of the modifying component (δ) to be tested.

3. Low mass flux data, from which the low mass flux modifying component could be verified.

3.2 Prandtl Number

When the Freon-12 correlation was being developed, the range of vapour Prandtl numbers investigated was only 0.9 to 1.02. Nevertheless, to retain the potential for a more generally applicable correlation, Green [1981b] argued that a function Pr_v^{-m} where $m = 0.1 + e^{-0.007\ L_s/D}$ should be included in the correlation. Furthermore, a preliminary examination of the CHF water data obtained by Lee [1965] showed that the correlation apparently applied to these conditions (see Figure 1).

However, when further CHF data for water are considered, the vapour Prandtl number may have a wider range of values so its effect may need to be re-examined more closely. Water data were, therefore, gathered for which the effect of changes in vapour Prandtl number could be considered exclusive of any short tube or low flow effects. Cumo et al. [1979], Dell et al. [1969], Bennett et al. [1965] and Lee [1965] are sources of such information. Comparison of these data with values calculated from the original Freon-12 correlation indicate that calculated values at L_s/D ratios of approx. 600 were approx. 5 per cent greater than those experimentally observed and, for L_s/D ratios of approx. 100, were approx. 10 per cent less than experimental data. Most of the data in Figure 1 can be considered as consistent with these trends. If all other parameters have been adequately taken into account, the implication is that the vapour Prandtl number index needs re-evaluation. The procedure adopted to do this was as follows:

1. After excluding the vapour Prandtl number term from the proposed correlation, the ratios of calculated to experimental CHF were obtained. These corresponded to differences in the range of approx. 25 to approx. 5 per cent depending upon (i) L_s/D ratio and (ii) the source of the experimental data (see Figures 2 to 5).

2. The mean lines drawn on Figures 2 to 5 were used to determine values of the vapour Prandtl number indices which would align average calculated CHFs with experimental data and these were plotted against L_s/D values on log:linear graph paper (see Figure 6).

3. In connection with the information shown on Figure 6, since the experimental data given by Dell et al. [1969] are at variance with other experimental data obtained for similar test conditions, their data were considered suspect and given little credence. From the remaining data, various relationships between vapour Prandtl number and L_s/D could be obtained. It was found, however, that the relationship which produced the least scatter between calculated and experimental CHF values, when all the data of Cumo et al. [1979], Bennett et al. [1965] and Lee [1965] were considered, was

$$q = -(0.22 + 0.6\, e^{-0.011\, L_s/D})$$

Note, however, that this re-estimated expression for the vapour Prandtl number index is still based upon only a relatively small range of vapour Prandtl numbers and that it may require further refinement when experimental data covering a wider range of vapour Prandtl numbers are examined.

3.3 Short Tube Modifier

The short tube modifying component of the Freon-12 correlation had been obtained from data covering

(i) a range of aspect ratios ($40 < L/D < 200$), and

(ii) various coolant conditions including different pressures;

nevertheless, it was considered that data from another fluid should be investigated.

To compare calculated with experimental values of CHF for water in relatively short tubes, selected data were used from table 6 of Thompson and Macbeth [1964]. The corresponding exit qualities for these data are > 0.1.

As can be seen from Figure 7, the calculated values overpredict the experimental data by up to approx. 20 per cent. This difference is greatest for the small aspect (L/D) ratios and indicates that the short tube modifying component was too large for water data.

In determining the modifying components in the original correlation, the effects on these components of all dimensionless groups were considered. However, only the Prandtl number was not varied to any significant extent; therefore, it may be postulated that any further changes to the modifying components of the correlation should include a vapour or liquid Prandtl number. Simple empirical alterations involving these dimensionless numbers were examined and it was found that, if a vapour Prandtl number was introduced into the modifier, in the following manner

$$\delta = e^{-0.14 * 10^8 \sigma_N} e^{-0.02(L/D)Pr_v} ,$$

much better agreement was obtained between the calculated and experimental values for water (see Figure 8). The inclusion of a vapour Prandtl number in this manner has no significant effect on the correlation for the Freon-12 data analysed, because the values of this Prandtl number for Freon-12 at these conditions were near unity (0.9 to 1.02).

3.4 Low Flow Modifier

When the original correlation was developed, only a limited amount of data was available for Freon-12 in which the mass flux was low (< 1000 kg s^{-1} m^{-2}). Therefore, when water data are compared with the correlation, the low flow modifying component of the correlation should be reconsidered.

A comparison of calculated values of CHF with experimental data taken from the Thompson and Macbeth [1964] table 6, for mass fluxes in the range 400 to 1000 kg s^{-1} m^{-2}, is shown in Figure 9. It can be seen that the agreement between calculated and experimental CHF values is reasonable with no marked trends. Hence, the low flow modifying component proposed in the original correlation was considered to be in satisfactory agreement with experimental data.

Note, however, that Thompson and Macbeth's table 6 also contains some CHF data for extremely low mass fluxes (down to 30 kg s^{-1} m^{-2}). For these conditions, the low flow modifying component of the correlation approaches 0.75 and no longer has a minor effect on the basic correlation. Under these circumstances, the correlation grossly overpredicts the experimental data and seems, therefore, unsuitable for flow conditions where the component δ_1 is greater than approx. 0.2.

3.5 Modified Correlation

The comparisons described in Sections 3.2, 3.3 and 3.4, suggest that the effect of Prandtl number in the proposed correlation should be modified; the correlation then becomes

$$\frac{\phi D}{\mu_v \lambda} = \frac{1}{17000} Re_v^n \left(\frac{\rho_\ell}{\rho_v}\right)^m Pr_v^q \left(\frac{\sigma}{\rho_v \lambda D}\right)^p f\left(L_s/D\right) (1+\delta)(1-\delta_1)$$

where $n = 1 - e^{-0.0067\, L_s/D}$

$$m = 0.1 + e^{-0.007\, L_s/D}$$

$$p = -0.5\,(0.15 + e^{-0.007\, L_s/D})$$

$$q = -(0.22 + 0.6\, e^{-0.011\, L_s/D})$$

$$f(L_s/D) = e^{4.25\, e^{-0.00366\, L_s/D}}$$

$$\delta = e^{-0.14 * 10^8 \sigma_N}\, e^{-0.02(L/D)Pr_v}$$

$$\delta_1 = 0.75\, e^{-BL/D \frac{G\sigma}{\rho_\ell \mu_\ell \lambda}}$$

$$B = 130.5\, e^{5.0\, e^{-0.02\, L/D}} \quad .$$

These modifications could not have been determined from the range of Freon-12 data examined by Green [1981] since they have negligible influence at those conditions.

4. COMPARISON OF CALCULATED AND EXPERIMENTAL CHF VALUES

Because only selected data from Cumo et al. [1979], Dell et al. [1969], Bennett et al. [1965] and Thompson and Macbeth [1964] were used to reassess the influence of Prandtl number on the proposed correlation, the correlation was next compared with all the CHF data published by these and other authors.

The results of these comparisons are shown in Table 1 and Figures 10 to 24.

5. DISCUSSION

As Table 1 and Figures 10 to 21 show, the CHF values calculated from the proposed correlation compare favourably with experimental data for water coolant conditions which

(i) are within the pressure range 3.4 to 12 MPa,

(ii) are for mass fluxes greater than 300 kg s^{-1} m^{-2}, and

(iii) have a dryout thermodynamic quality greater than 0.1.

Outside these ranges, however, the correlation can be much less accurate (see Figures 22 to 24).

At pressures higher than 13 MPa, the correlation tends to overpredict experimental data (Figure 22) and the ratio of calculated to experimental value has a wider variation. Campolunghi et al. [1974] published experimental information on water which showed that dryout qualities decrease markedly as pressure increases above approx. 10 MPa. They deduced, therefore, that different dryout mechanisms exist for pressures below and above 10 MPa. The comparison of calculated with experimental CHF values in this present work does not enable the observations made by Campolunghi et al. to be confirmed. Perhaps there is an upper limit around 10 to 12 MPa for this correlation when used for water, but further analysis is needed, particularly of experimental data for larger L_s/D ratios.

Examination of CHF data for low flow rates showed that, when the low flow modifying component (δ_1) becomes more than a relatively minor factor (i.e. greater than 0.2), there is a rapidly increasing disparity between calculated and experimental CHF values. This indicates that a substantially different correlation needs to be developed for low flow rates. This observation is similar to that of Macbeth [1963] who considered that there are two distinct CHF regimes; high flow rate and low flow rate.

At low quality local conditions CHF values from the correlation are, in general, marginally higher than the experimental data and have greater variability (see Figures 23 and 24). This could be caused by either or both

- difficulties in determining L_s/D precisely,
- discrepancies arising from the assumption of thermal equilibrium.

Both of these have been discussed previously by Green [1981b].

If data which were

(i) outside a pressure range 3.4 to 12 MPa,

(ii) for mass fluxes less than approx. 300 kg s^{-1} m^{-2}, and

(iii) determined at a local thermodynamic quality less than 0.1,

are excluded the agreement between calculated and experimental values is very similar to that observed with Freon-12 data; i.e. as the magnitude of L_s/D increases, the variation and magnitude of the error between calculated and experimental data, becomes less. Apart, however, from the data of Cumo et al. [1979], Bennett et al. [1965] and Lee [1965], the scatter of this ratio of calculated to experimental CHF over the whole range of dimensionless saturation lengths is greater than observed for Freon-12. Thus, for dimensionless saturation lengths (L_s/D) greater than 200, the correlation calculates experimental data to within approx. ± 8 per cent, whereas for L_s/D values less than 200, variation between calculated and experimental CHF may be as high as approx. 20 per cent. (Such variations usually occur at very low L_s/D ratios.) For all data within the ranges specified (some 2063 data points) irrespective of L_s/D ratio, the mean ratio of the calculated to experimental CHF is 0.982 and the r.m.s. error 5.8 per cent.

6. CONCLUSIONS

The empirical CHF correlation developed from examining Freon-12 data has been compared with experimental data for water upflow in uniformly heated vertical tubes. It was necessary to re-estimate the index of the vapour Prandtl number and to include a vapour Prandtl number term in the short tube modifying factor. Both of these changes are relatively minor. They could not have been determined from examination of the Freon-12 data alone, since the vapour Prandtl number for those data varies little from unity.

The correlation is, therefore, that given in Section 3.5.

Comparison of values calculated from this correlation with 2063 experimental data for water upflow in uniformly heated vertical tubes which satisfy the following coolant conditions:

(1) within the pressure range 3.4 to 12 MPa,

(2) mass fluxes greater than approx. 300 kg s^{-1} m^{-2}, and

(3) local thermodynamic quality greater than 0.1,

shows that there is very good agreement, the mean ratio of the calculated to experimental CHF being 0.982 and the r.m.s. error 5.8 per cent.

7. REFERENCES

Bennett, A.W., Hewitt, G.F., Kearsey, H.A. and Keeys, R.K.F. [1965] - Measurements of burnout heat flux in uniformly heated round tubes at 1000 psia. AERE R5055.

Cumo, M., Palazzi, G. and Urbani, G.C. [1979] - On the limiting critical quality and the 'Deposition Controlled' burnout. CNEN-RT/ING(79)4.

Campolunghi, F., Cumo, M., Ferrari, G., Leo, R. and Vaccaro, G. [1974] - Burnout power in once-through tubular steam generators, Paper B6.9, Proc. Fifth International Heat Transfer Conf., Tokyo, Vol.IV, p.280.

Dell, F.R., Hewitt, G.F., Keeys, R.K.F. and Stinchcombe, R.A. [1969] - Burnout heat flux measurements in a long tube. AERE M2216.

Green, W.J. [1978] - An experimental and analytical study of transient heat transfer in the region of dryout for a heated tube using Freon-12 as coolant. AAEC/E452.

Green, W.J. and Lawther, K.R. [1979] - An investigation of transient heat transfer in the region of flow boiling dryout with Freon-12 in a heated tube. Nucl. Eng. Des. 55:131-144.

Green, W.J. and Lawther, K.R. [1980] - An experimental study of dryout heat transfer in tubes by a temperature transient method. ANS-ASME Topical Meeting on Nuclear Reactor Thermohydraulics, Saratoga, October 1980.

Green, W.J. [1981a] - An investigation of critical heat fluxes in vertical tubes internally cooled by Freon-12. Part I: Experimental investigations into the effects of axially uniform and non-uniform heating. AAEC/E517.

Green, W.J. [1981b] - An investigation of critical heat fluxes in vertical tubes internally cooled by Freon-12. Part II: The development of an accurate critical heat flux correlation for uniformly heated tubes. AAEC/E528.

Lee, D.H. [1965] - An experimental investigation of forced convection burnout in high pressure water. Part III: Long tubes with uniform and non-uniform axial heating. AEEW R355.

Lee, D.H. [1966] - An experimental investigation of forced convection burnout in high pressure water. Part IV: Large diameter tubes at about 1600 psi. AEEW R479.

Lee, D.H. and Obertelli, J.D. [1963] - An experimental investigation of forced convection burnout in high pressure water. Part I: Round tubes with uniform flux distribution. AEEW R213.

Macbeth, R.V. [1963] - Burnout analysis. Part III: The low velocity burnout regime. AEEW R222.

Thompson, B. and Macbeth, R.V. [1964] - Boiling water heat transfer - burnout in uniformly heated round tubes: A compilation of world data with accurate correlations. AEEW R356.

8. NOMENCLATURE

B	variable defined in text
C_p	specific heat
CHF	critical heat flux
D	tube bore
G	mass flux
k	thermal conductivity
L	total heated length
L_s	saturation boiling length
m, n, p, q	indices defined in text
Pr	Prandtl number = $C_p\ \mu/k$
Re_v	vapour Reynolds number = $DV_v\rho_v/\mu_v = DV\rho_v/\mu_v$ (for slip ratio of 1) $= \frac{GD}{\mu_v}\ (x+(1-x)\ \rho_v/\rho_\ell)$
V	velocity
x	mass fraction (quality)
δ	short tube modifying factor
δ_1	low mass flux modifying factor

ρ	density
μ	viscosity
σ	surface tension
σ_N	surface tension number = $\sigma/(D\lambda\rho_v)$
λ	latent heat of vaporisation
ϕ	critical heat flux
ϕ_N	critical heat flux number = $\phi D/(\lambda\mu_v)$

Subscripts

v	vapour
ℓ	liquid

TABLE 1

CRITICAL HEAT FLUX DATA FOR VERTICAL UPFLOW OF WATER IN ROUND TUBES

Source of Data	Pressure (MPa)	Exit Quality	Tube Bores (cm)	Heated Length (cm)	Mass Flux (kg s^{-1} m^{-2})	No. of Data Examined	Mean Ratio of Calculated to Experimental CHF	r.m.s. Error (%)	Comments	Fig.
Cumo et al. [1979]	7.0	0.44 → 1.064	1.29	1000	300 → 2040	190*	1.003	1.5		12
Dell et al. [1969]	6.9	0.14 → 0.78	0.62	91 → 552	1330 → 4140	82*	0.97	4.6		11
Bennett et al. [1965]	6.6 → 7.1	0.1 → 0.95	0.92 → 1.26	173 → 556	620 → 5550	161*	1.008	3.7	Excluding Table 1 and all data where x <0.1 in other tables	13
Lee [1965]	6.4 → 7.2	0.1 → 0.45	0.95 → 1.18	84 → 366	2000 → 4120	132*	1.005	3.1	Excluding x ≦0.1 data	10
Lee & Obertelli [1963]	3.7 → 11.1	0.1 → 0.99	0.56 → 1.15	21 → 200	400 → 4220	493*	0.973	5.8	Excluding x ≦0.1 data	14
	3.7 → 11.1	0 → 0.1	0.56 → 1.15	21 → 173	1030 → 4220	104	1.023	13.4	Only for data where 0 < x ≦ 0.1	23
Lee [1966]	8.2 → 12.6	0.1 → 0.73	1.41 → 4.47	64 → 152	340 → 2710	262*	0.97	9.6	Excluding x ≦ 0.1 data	15
	8.6 → 12.5	0 → 0.1	1.41 → 4.47	64 → 127	675 → 3410	135	0.933	10.8	Only for data where 0 < x ≦ 0.1	24
Thompson & Macbeth [1964] Table 4	3.4 → 4.4	0.1 → 0.9	0.47 → 1.08	21 → 173	400 → 4160	163*	0.98	5.7	Excluding (i) all inconsistent data as indicated by Thompson & Macbeth (ii) x ≦ 0.1 data (iii) G < 400 kg s^{-1} m^{-2} data	16

(Continued)

TABLE 1 (Continued)

Source of Data	Pressure (MPa)	Exit Quality	Tube Bores (cm)	Heated Length (cm)	Mass Flux (kg s^{-1} m^{-2})	No. of Data Examined	Mean Ratio of Calculated to Experimental CHF	r.m.s. Error (%)	Comments	Fig.
Thompson & Macbeth [1964] Table 5	4.9 → 5.2	0.15 → 0.9	0.56	43 → 173	100 → 4220	31*	0.96	4.5	Excluding x ≤ 0.1 data	17
Thompson & Macbeth [1964] Table 6	6.6 → 7.3	0.1 → 0.95	0.46 → 3.75	21 → 366	400 → 7270	451*	0.98	4.7	Excluding (i) all inconsistent data as indicated by Thompson & Macbeth (ii) x ≤ 0.1 data	18
Thompson & Macbeth [1964] Table 7	6.8 → 9.1	0.11 → 0.52	0.57 → 1.15	62 → 152	1020 → 4070	15*	0.989	8.4	Excluding x ≤ 0.1 data	19
Thompson & Macbeth [1964] Table 8	10.4 → 11.2	0.1 → 0.59	0.46 → 1.98	23 → 152	400 → 4070	83*	0.972	8.0	Excluding (i) all inconsistent data as indicated by Thompson & Macbeth (ii) x ≤ 0.1 data	20
Thompson & Macbeth [1964] Table 9	12.1 → 12.6	0.01 → 0.4	0.19 → 1.98	15 → 91	400 → 4000	33	0.957	8.5	Excluding x ≤ 0.01 data	21
Thompson & Macbeth [1964] Table 10	13.8	0.1 → 0.8	0.46 → 1.05	30 → 183	225 → 4960	152	1.029	12.0	Excluding (i) x ≤ 0.1 data (ii) G < 200 kg s^{-1} m^{-2} data	22
			Overall mean values for 2063 data marked *				0.982	5.8		

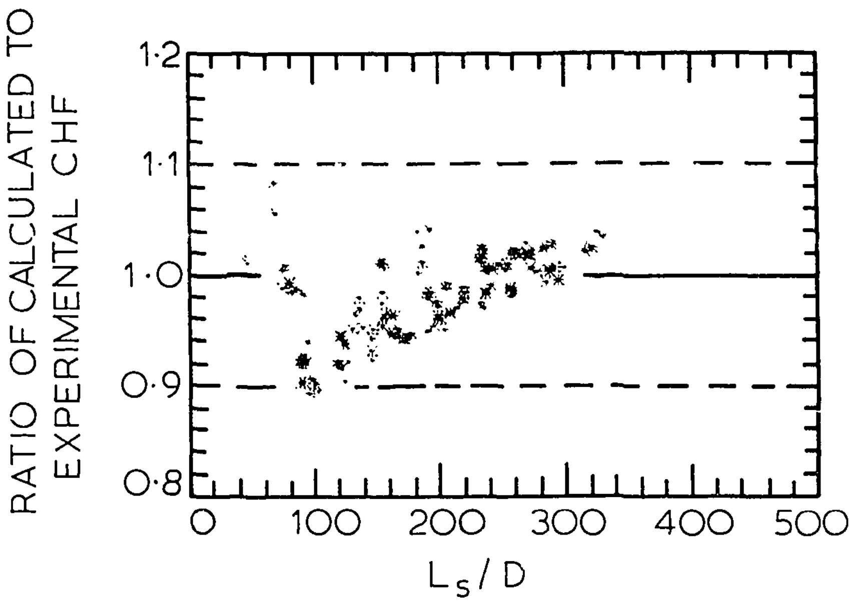

Figure 1 Comparison of experimental CHF data and values calculated from the original Freon-12 correlation (Lee [1965] data)

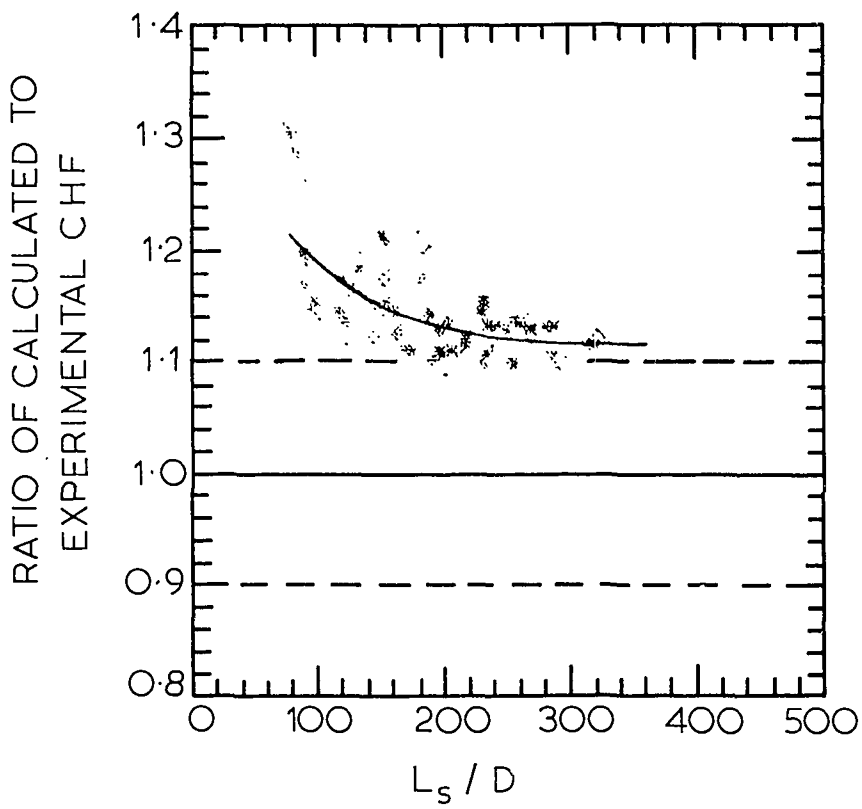

Figure 2 Comparison of experimental CHF data and values calculated from the original Freon-12 correlation excluding Prandtl number term (Lee [1965] data)

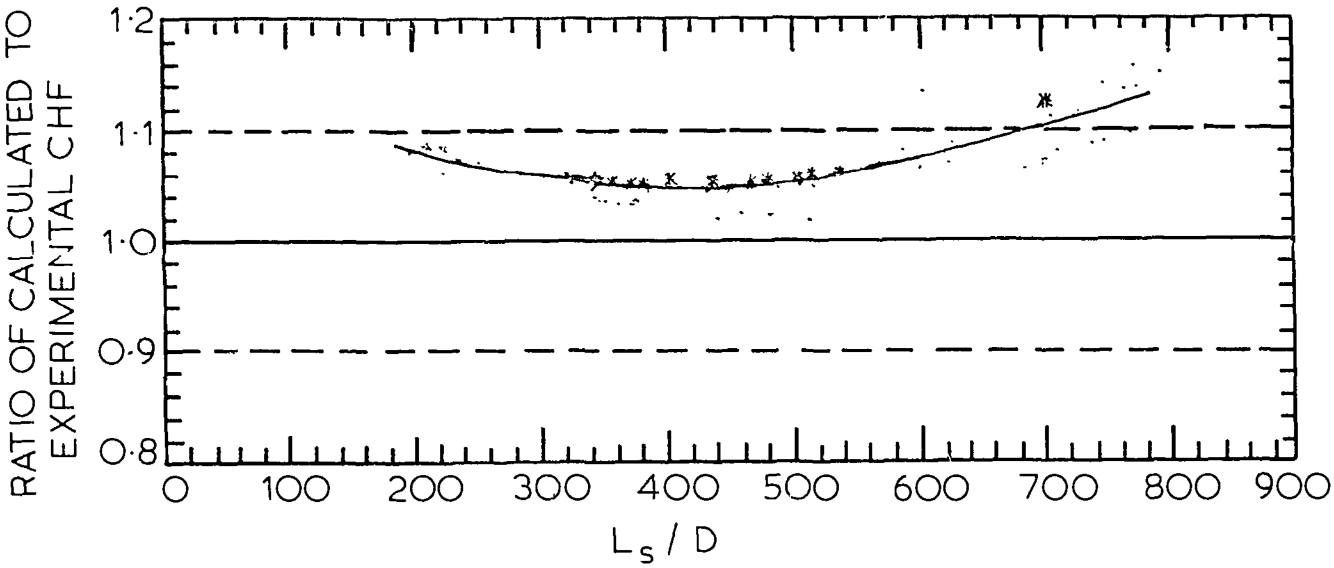

Figure 3 Comparison of experimental CHF data and values calculated from the original Freon-12 correlation excluding Prandtl number term (Dell et al. [1969] data)

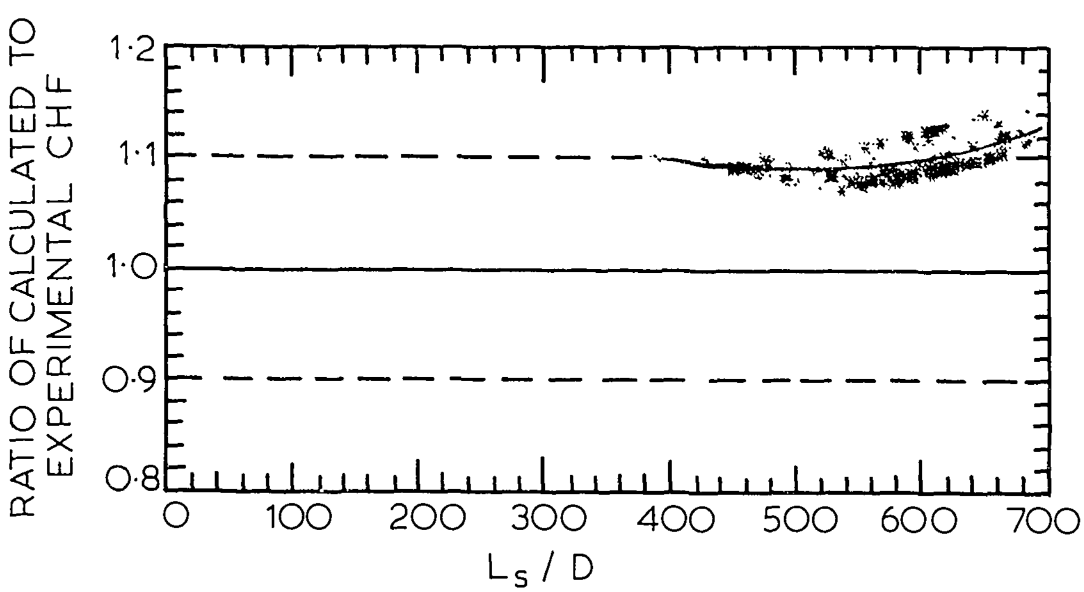

Figure 4 Comparison of experimental CHF data and values calculated from the original Freon-12 correlation excluding Prandtl number term (Cumo et al. [1979] data)

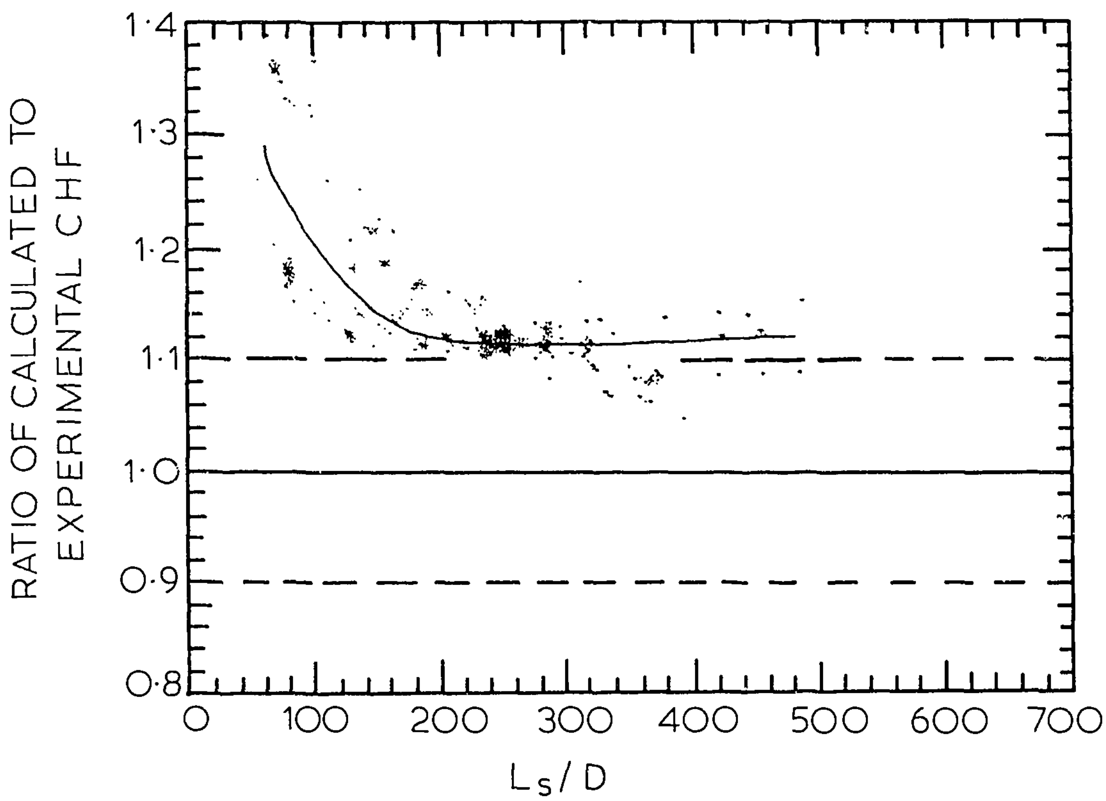

Figure 5 Comparison of experimental CHF data and values calculated from the original Freon-12 correlation excluding Prandtl number term (Bennett et al. [1965] data)

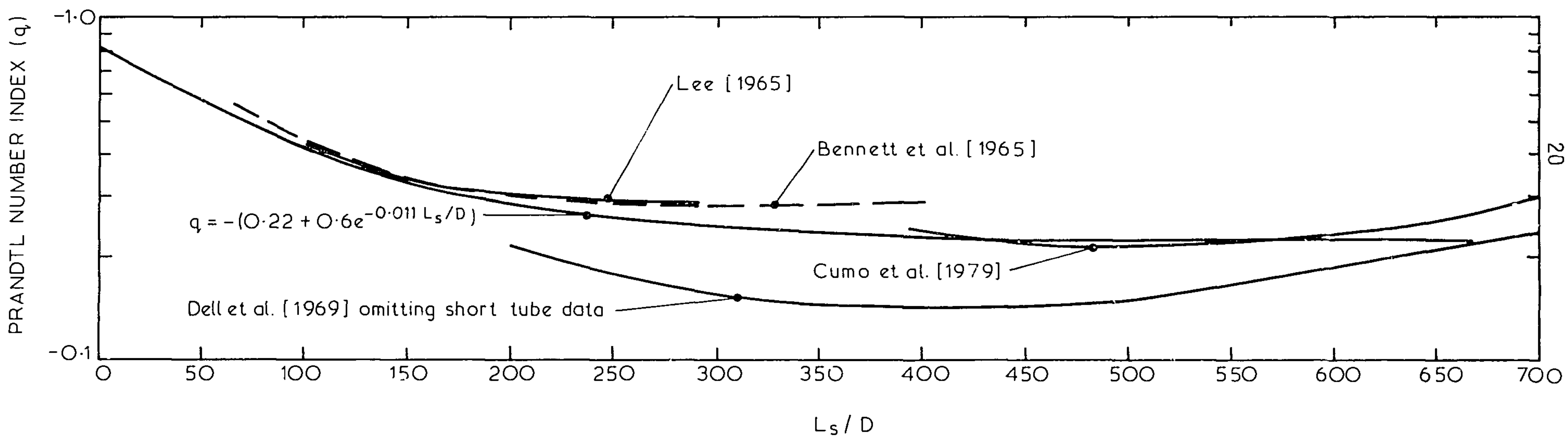

Figure 6 Relationship between Prandtl number index and L_s/D

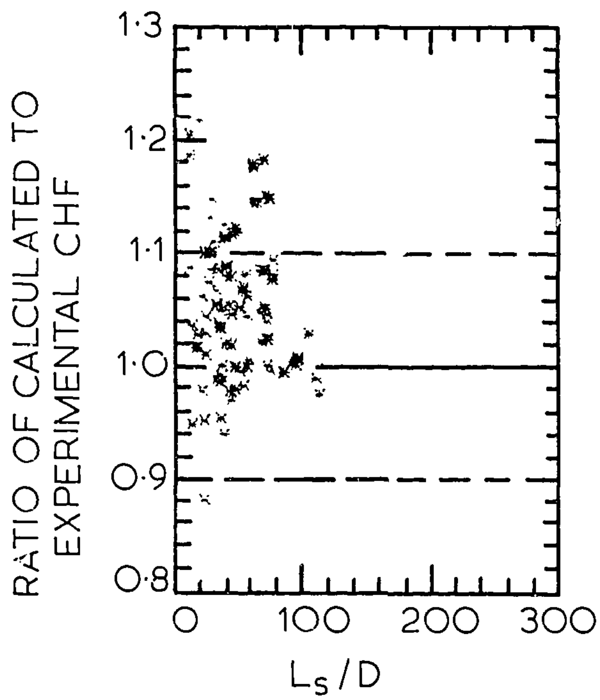

Figure 7 Comparison of experimental CHF data and values calculated from the original Freon-12 correlation modified to include revised Prandtl number term in the basic correlation (Thompson and Macbeth [1964] table 6 short tube data)

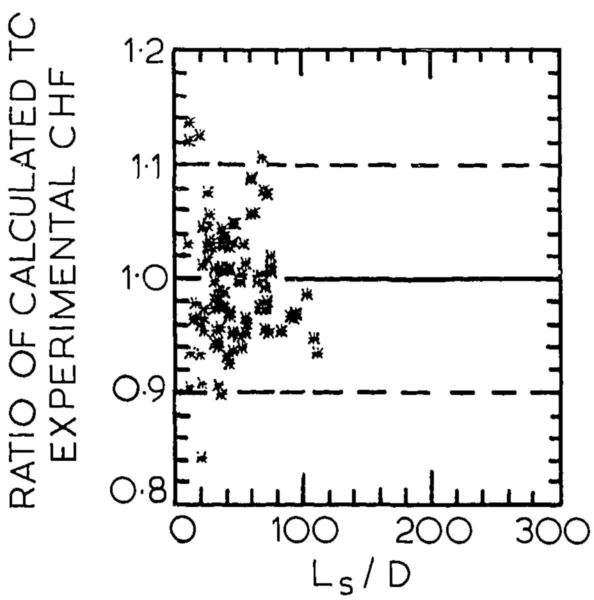

Figure 8 Comparison of experimental CHF data and values calculated from the original Freon-12 correlation modified to include Prandtl number terms both in the basic correlation and in the short tube component (Thompson and Macbeth [1964] table 6 short tube data)

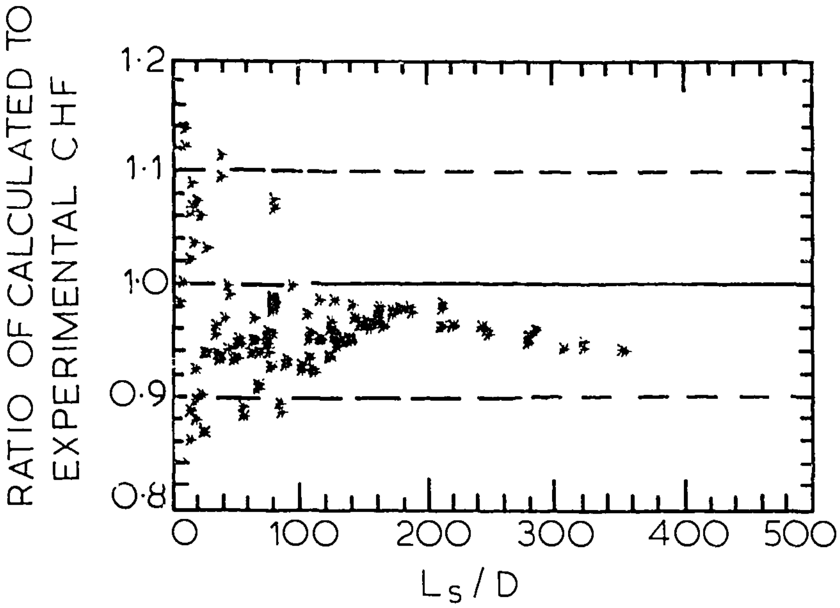

Figure 9 Comparison of calculated and experimental CHF values using data where 400 < G < 1000 kg s^{-1} m^{-2} (Thompson and Macbeth [1964] table 6 data)

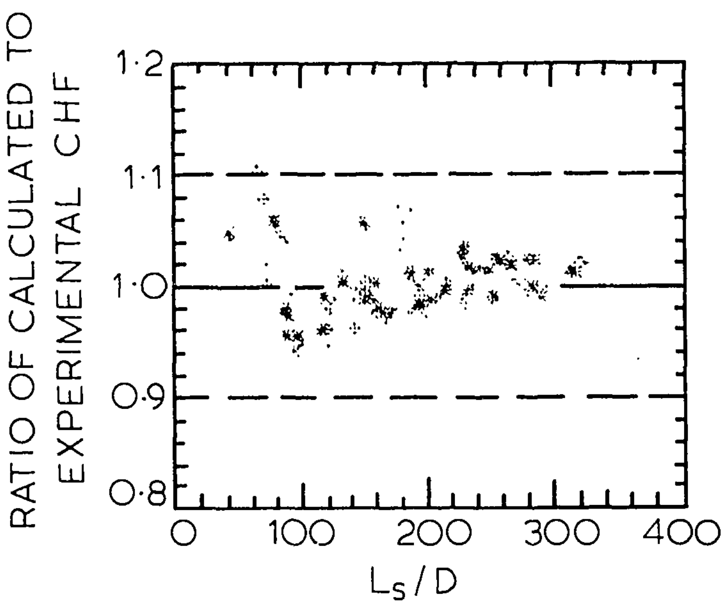

Figure 10 Comparison of calculated and experimental CHF values (Lee [1965] data, x > 0.1)

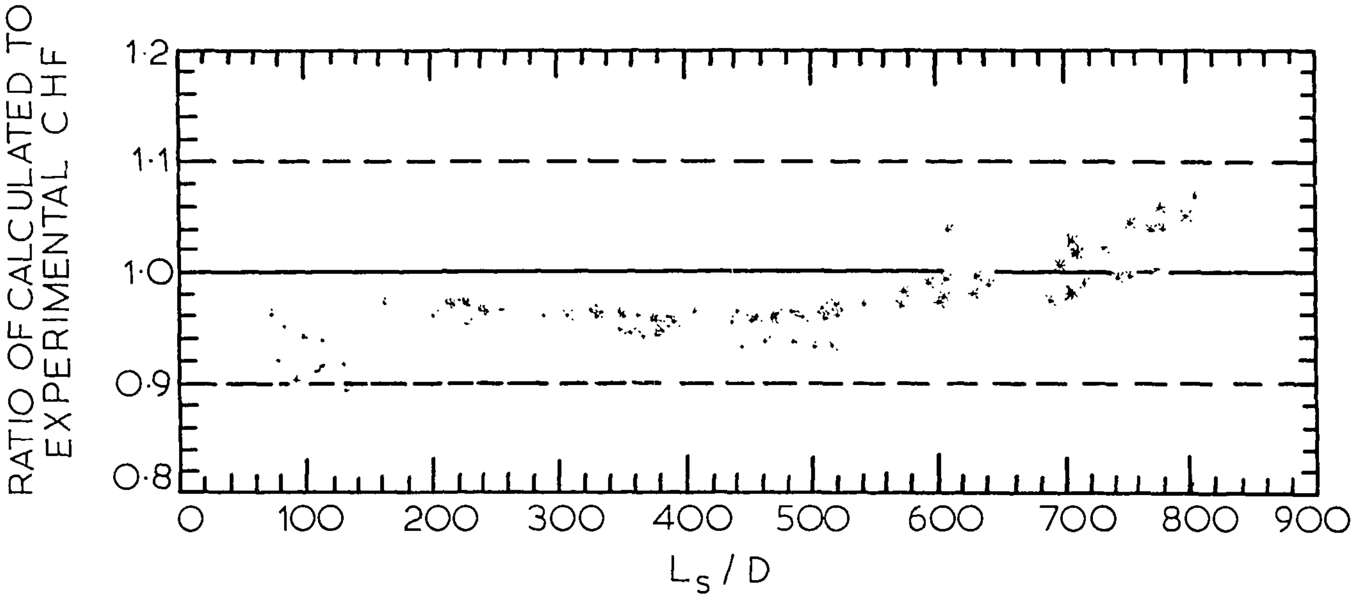

Figure 11 Comparison of calculated and experimental CHF values (Dell et al. [1969] data)

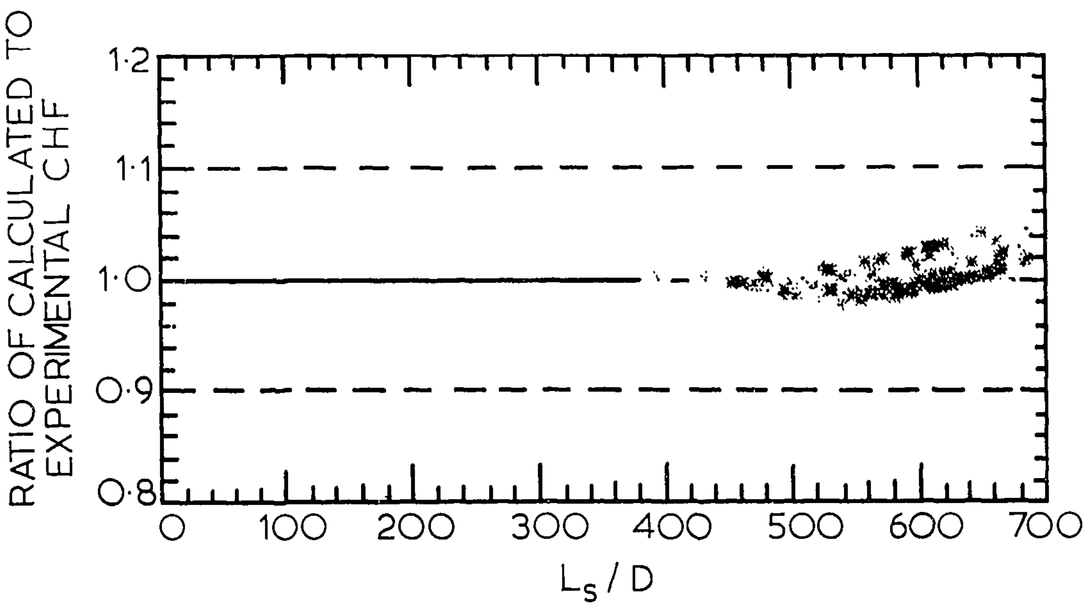

Figure 12 Comparison of calculated and experimental CHF values (Cumo et al. [1979] data)

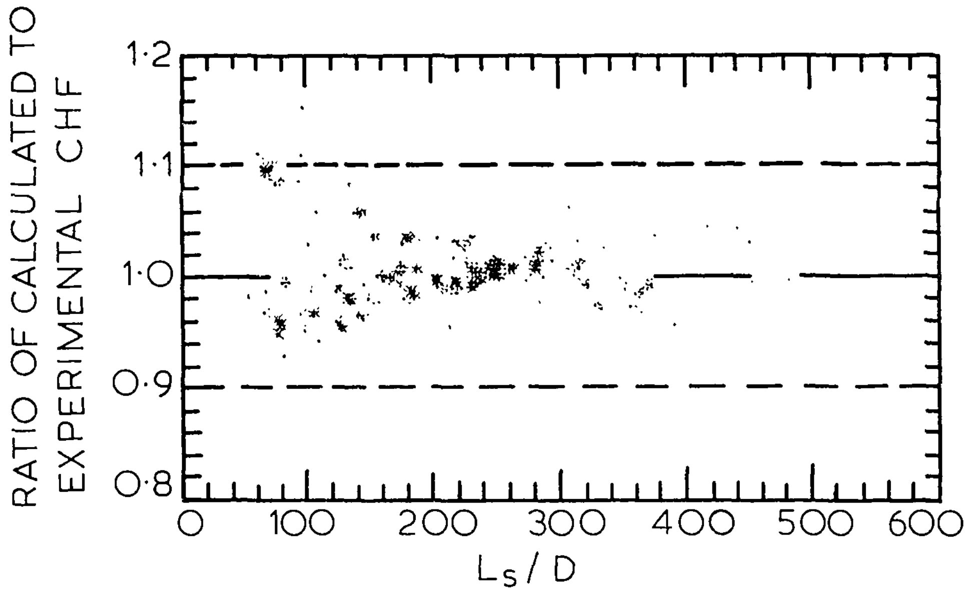

Figure 13 Comparison of calculated and experimental CHF values [Bennett et al. [1965] data, x > 0.1)

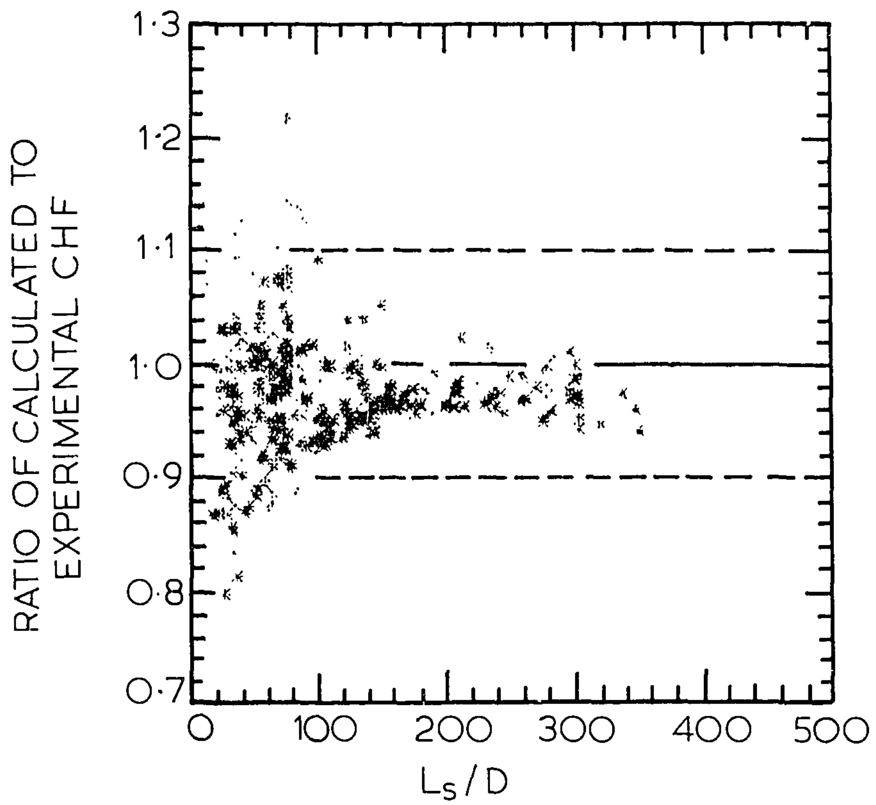

Figure 14 Comparison of calculated and experimental CHF values (Lee and Obertelli [1963] data, x > 0.1)

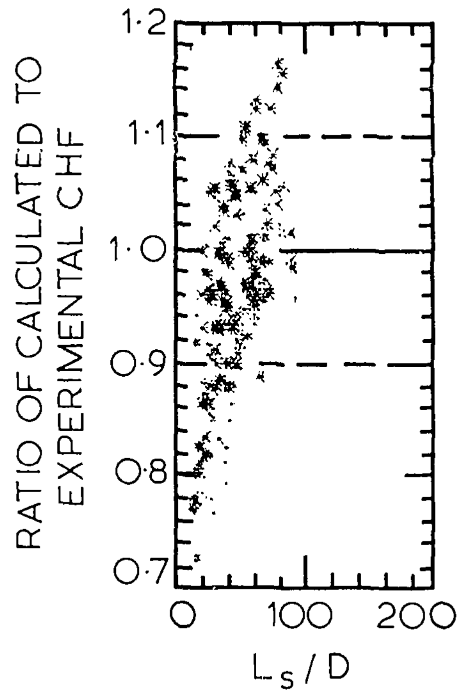

Figure 15 Comparison of calculated and experimental CHF values (Lee [1966] data, x > 0.1)

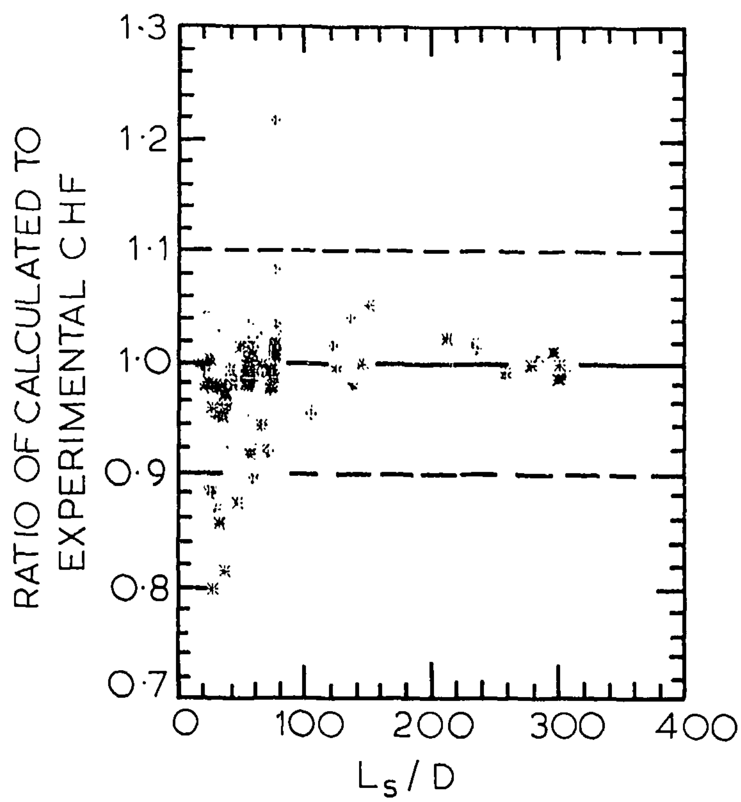

Figure 16 Comparison of calculated and experimental CHF values (Thompson and Macbeth [1964] table 4 data, x > 0.1)

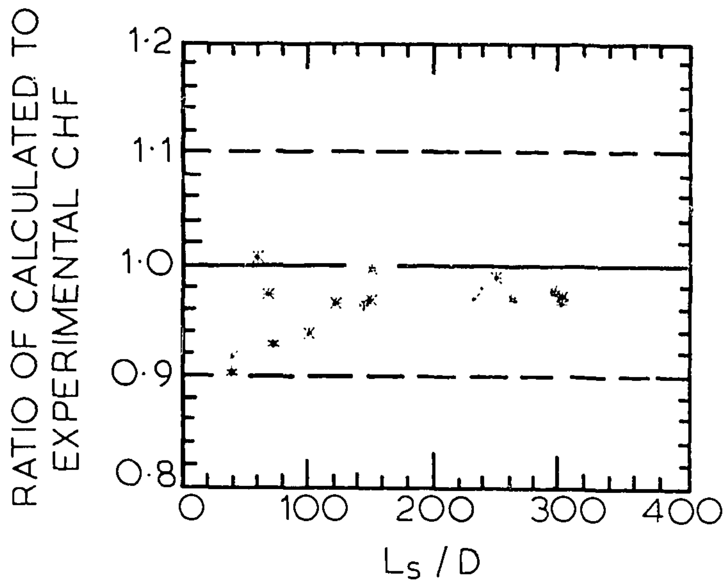

Figure 17 Comparison of calculated and experimental CHF values (Thompson and Macbeth [1964] table 5 data, x > 0.1)

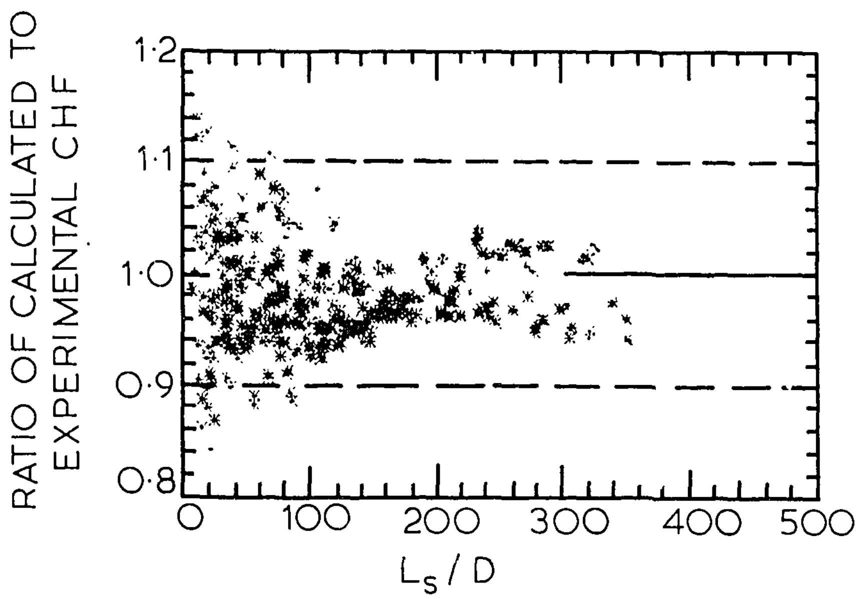

Figure 18 Comparison of calculated and experimental CHF values (Thompson and Macbeth [1964] table 6 data, x > 0.1)

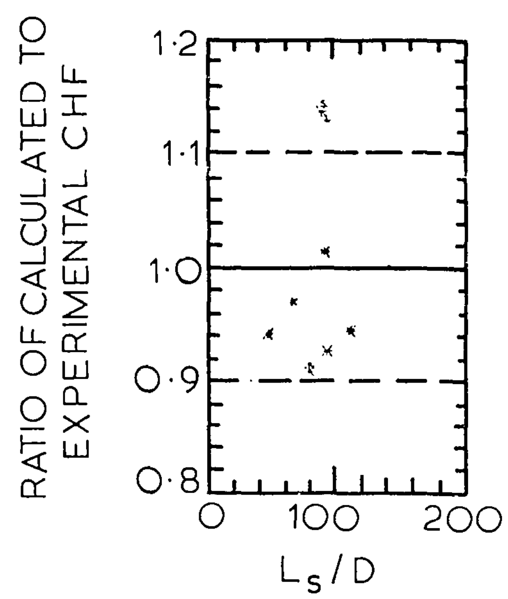

Figure 19 Comparison of calculated and experimental CHF values (Thompson and Macbeth [1964] table 7 data, x > 0.1)

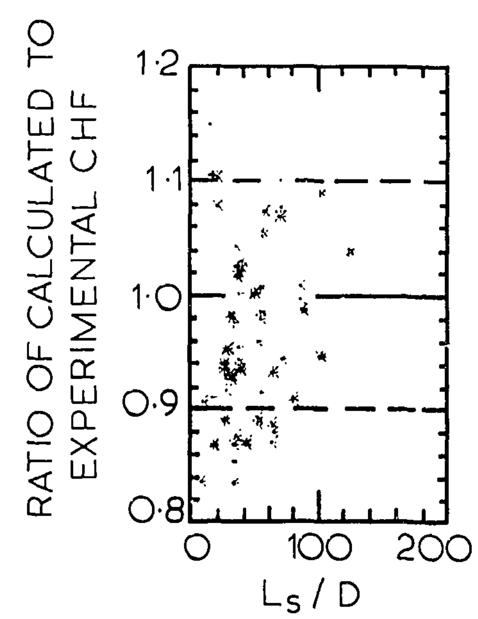

Figure 20 Comparison of calculated and experimental CHF values (Thompson and Macbeth [1964] table 8 data, x > 0.1)

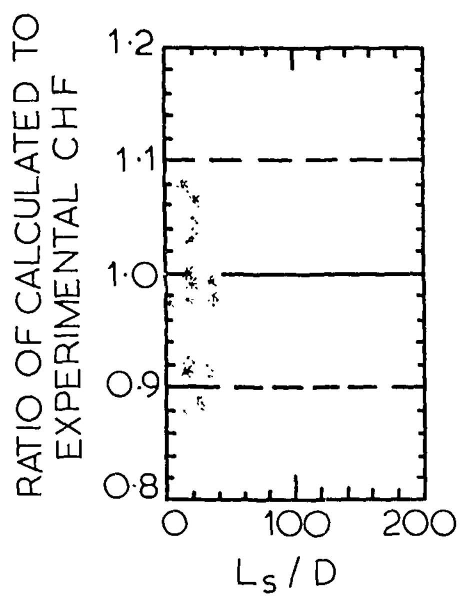

Figure 21 Comparison of calculated and experimental CHF values (Thompson and Macbeth [1964] table 9 data, x > 0.01)

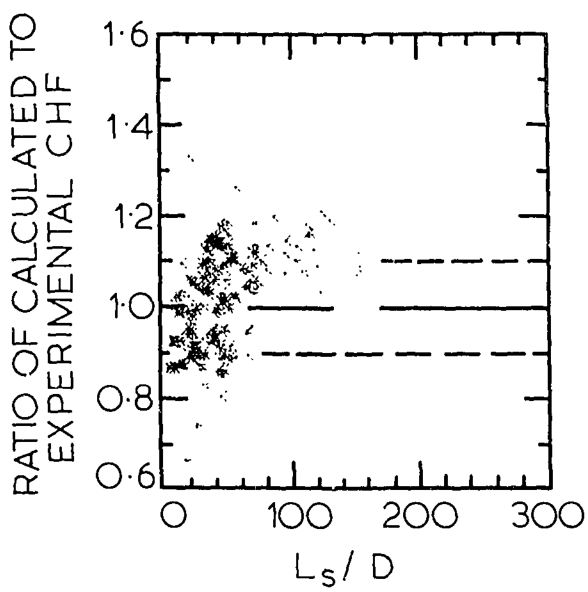

Figure 22 Comparison of calculated and experimental CHF values (Thompson and Macbeth [1964] table 10 data, x > 0.1)

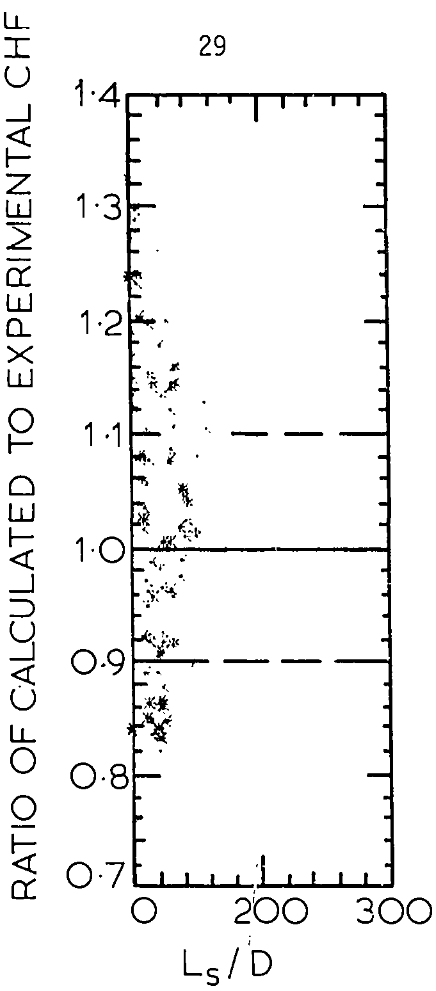

Figure 23 Comparison of calculated and experimental CHF values (Lee and Obertelli [1963] data, 0 < x < 0.1)

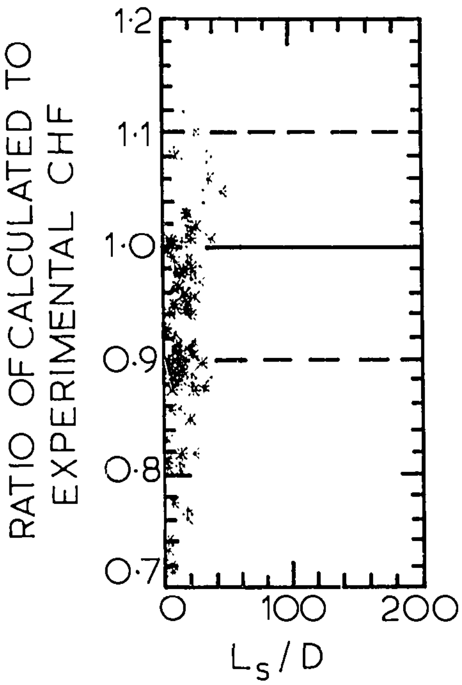

Figure 24 Comparison of calculated and experimental CHF values (Lee [1966] data, 0 < x < 0.1)