Int. J. Heat Mass Transfer. Vol. 30, No. 11, pp. 2261–2269, 1987
Printed in Great Britain

0017-9310/87 $3.00+0.00

Critical heat flux of forced convective boiling in uniformly heated vertical tubes with special reference to very large length-to-diameter ratios

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(*Received* 16 *January* 1987)

Abstract—Over a wide range of length-to-diameter ratios l/d extending from 50 to 800, the systematic nature of the critical heat flux (CHF) in tubes is explored by analyzing CHF data upto 1051, which have recently been obtained in experiments of R-12 at 1.47 MPa for a tube diameter $d = 3$, 5 and 8 mm, and a mass velocity $G = 510$–6055 kg m^{-2} s^{-1}. First, concrete evidence is obtained to show the unfitness of the expedient method substituting CHF data in tubes of low l/d values with subcooling enthalpy $\Delta H_i < 0$ for those in tubes of very high l/d values with $\Delta H_i > 0$. Next, the CHF data with $\Delta H_i > 0$ are analyzed on the basis of two typical kinds of existing generalized correlations of CHF data, showing a fact that the value of CHF for tubes of diameter as small as 3 or 5 mm tends to deviate from standard values predicted by the foregoing generalized correlations based on the CHF data for l/d less than, say, 370. A tentative means to predict the above-mentioned deviation peculiar to long and narrow tubes is also obtained.

1. INTRODUCTION

EXPERIMENTS on the critical heat flux (CHF) of forced convective boiling in uniformly heated vertical tubes with subcooled inlet conditions have already been reported in numerous papers, but the experiments for a length-to-diameter ratio $l/d > 370$ are very limited. To the authors' knowledge, water data compiled by Thompson and Macbeth [1] include a few data for $l/d = 528$ and 792 ($d = 3.9$ mm). Thereafter, Matzner *et al.* [2] carried out experiments with water for $l/d \leqslant 480$ ($d = 10.2$ mm); Dell *et al.* [3] with water for $l/d \leqslant 893$ ($d = 6.2$ mm); Becker *et al.* [4] with water for $l/d \leqslant 500$ ($d = 10$ mm); Campolunghi *et al.* [5] with water for $l/d \leqslant 938$ ($d = 12$ mm); Wurtz [6] with water for $l/d \leqslant 800$ ($d = 10$ mm); and Merilo and Ahmad [7] with R-12 for $l/d \leqslant 576$ ($d = 5.3$ mm). Among the foregoing, however, the above-mentioned data included in ref. [1] are of disordered conditions, the experiments of ref. [4] are concerned with CHF in a rather special regime of very high vapor-to-liquid density ratio $\rho_l/\rho_v > 0.14$, and some of the other papers do not give full experimental details. In such a limited state of data, the systematic nature of CHF under normal conditions of ρ_l/ρ_v has not yet been clarified as well for very high values of l/d.

On the other hand, as is well known, the exit quality χ_{ex} for a uniformly heated tube is related to the critical heat flux q_c as

$$\chi_{ex} = 4\frac{q_c}{GH_{fg}}\frac{l}{d} - \frac{\Delta H_i}{H_{fg}} \tag{1}$$

where H_{fg} is the latent heat of evaporation. Usually, CHF in tubes of very high l/d ratios with $\Delta H_i > 0$ takes place at $\chi_{ex} > 0$; accordingly, an idea may arise that the state of causing CHF in very long tubes with $\Delta H_i > 0$ can be conveniently approximated by that in short tubes with $\Delta H_i < 0$. In the latter case with $\Delta H_i < 0$, however, even though the value of ΔH_i is fixed, two-phase flow at the tube inlet is allowed to have various flow configurations; hence, several discrepancies have been noted from the generality of the result (cf. Collier [8] and Hewitt [9]). However, a means to correlate q_c as a function of χ_{ex} for fixed p, d and G values has been widely used; and in this type of data correlation, CHF data for $\Delta H_i < 0$ are apt to be used together with the data for $\Delta H_i > 0$ making no distinction between them. Moreover, a peculiar form of the q_c vs χ_{ex} correlation curve thus obtained has so far been assumed by some investigators to be closely connected with changes in CHF mechanism (cf. Doroschuk *et al.* [10]). In this sense, therefore, CHF in short tubes with $\Delta H_i < 0$ can have a strong relation to the problems of CHF in tubes of very high l/d values with $\Delta H_i > 0$.

In order to throw light on the foregoing problems, the authors have recently conducted systematic experiments; and this paper reports the result of analyzing the obtained data.

NOMENCLATURE

d	internal tube diameter [m]
G	mass velocity [kg m^{-2} s^{-1}]
H_{fg}	latent heat of evaporation [J kg^{-1}]
ΔH_i	inlet subcooling enthalpy [J kg^{-1}]
l	heated tube length [m]
l_b	boiling length [m]
p	system pressure [Pa]
Δp	static pressure difference through heated tube [Pa]
q_c	critical heat flux [W m^{-2}]
q_{c0}	critical heat flux at $\Delta H_i = 0$ [W m^{-2}].

Greek symbols

μ_l	viscosity of liquid [Pa s]
μ_v	viscosity of vapor [Pa s]
ρ_l	density of liquid [kg m^{-3}]
ρ_v	density of vapor [kg m^{-3}]
σ	surface tension [N m^{-1}]
ψ_k	mass flux parameter, $(G^2 d/\sigma\rho_l)^{1/2}$ [—]
χ_{ex}	exit quality at CHF conditions [—].

2. EXPERIMENT AND EXPERIMENTAL DATA

Due to the ceiling height restriction of the laboratory, the initial experiments were conducted with tubes of $d = 3$ mm and $l/d = 50$–800, for which R-12 at 1.47 MPa (with a comparatively high value of $\rho_v/\rho_l = 0.0735$) was chosen as a test fluid to hold down the value of the specific volume of vapor as well as that of the relative pressure drop $\Delta p/p$ through the heated tube. It was then followed by experiments for $d = 5$ mm and $l/d = 50$–600 in the same laboratory; and finally, outdoor experiments were performed with tubes of $d = 8$ mm and $l/d = 50$–800. These series of experiments have already been reported in refs. [11–13], respectively.

The experimental apparatus employed in the above experiments are principally the same as that of Katto and Ohno [14], so further details are omitted here. The test tube is a stainless steel tube (wall thickness: 0.5 mm for $d = 3$ mm, 1 mm for $d = 5$ mm, and 2 mm for $d = 8$ mm) heated by the direct passage of a d.c. current. A test section including the test tube is formed in such a manner as shown in Fig. 1, which enables not only the experiments of $\Delta H_i > 0$ for $l/d = 50$–800 to be carried out, but also the experiments of $\Delta H_i < 0$ for the same test tube of $l/d = 50$–200 with the help of a preheater, which is located upstream of the test tube, and is heated by the direct passage of a separate d.c. current.

An example of experimental data collected in these experiments is represented in Fig. 2. In the right-hand region of Fig. 2 for $\Delta H_i > 0$, it will be noticed that, for tubes of high l/d ratios, the critical heat flux q_c has a linear relationship with ΔH_i, while when l/d is low, the q_c vs ΔH_i relationship is nonlinear with a change of gradient midway. This phenomenological feature of q_c is similar to that which has already been pointed out in various publications (see, e.g. ref. [15]).

Table 1 shows the number of experimental data obtained for each set of d, G and l/d, totaling 1146.† Among them, however, 95 data (a breakdown list is shown in Table 2) suffer from comparatively large

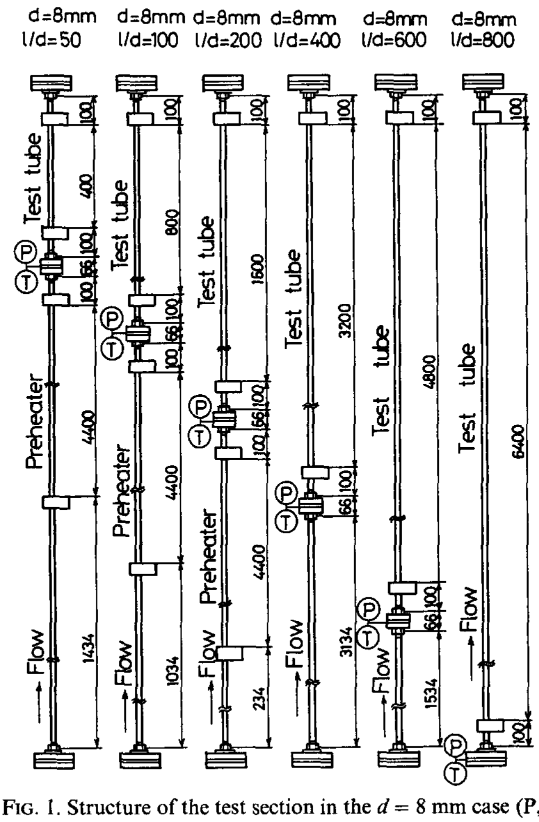

Fig. 1. Structure of the test section in the $d = 8$ mm case (P, pressure gauge; T, thermocouple).

pressure drops through the test tube $\Delta p/p > 0.1$, and accordingly, have been excluded in the following analysis.

3. ANALYSIS OF EXPERIMENTAL DATA

3.1. *Correlation of q_c/GH_{fg} vs χ_{ex} ($\Delta H_i < 0$)*

Recently, Groeneveld *et al.* [16] presented a table to predict the critical heat flux q_c through the following generalized relationship:

$$\frac{q_c}{GH_{fg}} = f\left(\chi_{ex}, \frac{\rho_l}{\rho_v}, \psi_k\right) \tag{2}$$

where ψ_k is the mass flux parameter defined as

† A complete list of experimental data is available from the authors.

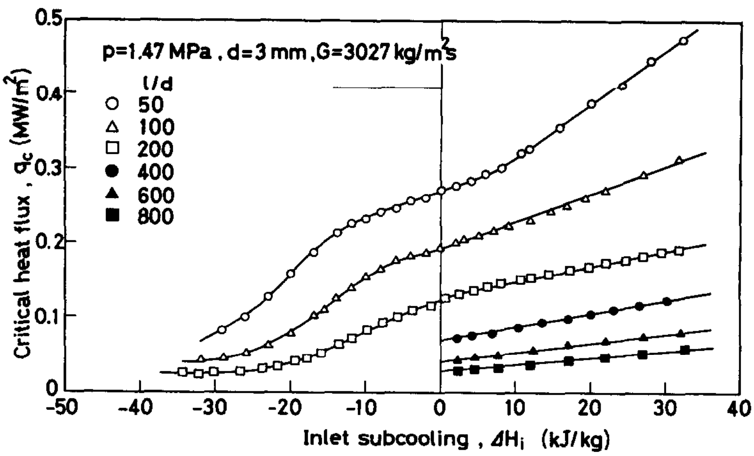

FIG. 2. An example of the experimental data of CHF.

Table 1. Breakdown list of the number of experimental data†

d (mm)	G (kg m^{-2} s^{-1})	l/d 50	100	200	400	600	800	$\Delta H_i/H_{fg}$ (mean)
3	1362	30(18)	31(20)	29(18)	9(0)	8(0)	8(0)	$-0.41 \sim 0.29$
3	3027	24(12)	26(14)	31(16)	10(0)	8(0)	8(0)	$-0.27 \sim 0.28$
3	4844	23(10)	26(13)	27(12)	12(0)	8(0)	11(0)	$-0.23 \sim 0.27$
3	6055	21(8)	23(10)	25(11)	9(0)	8(0)	5(0)	$-0.19 \sim 0.26$
5	545	21(12)	23(12)	24(10)	14(0)	15(0)	—	$-0.34 \sim 0.31$
5	1090	22(10)	22(10)	22(10)	14(0)	14(0)	—	$-0.37 \sim 0.28$
5	2180	19(8)	19(8)	19(9)	14(0)	13(0)	—	$-0.28 \sim 0.26$
5	3270	19(8)	19(7)	19(7)	13(0)	13(0)	—	$-0.18 \sim 0.25$
8	510	25(17)	26(17)	25(17)	11(0)	12(0)	11(0)	$-0.66 \sim 0.28$
8	1020	22(14)	20(12)	22(13)	11(0)	11(0)	10(0)	$-0.49 \sim 0.26$
8	2040	17(9)	17(9)	17(9)	10(0)	10(0)	10(0)	$-0.34 \sim 0.24$
8	3060	17(9)	17(9)	17(9)	10(0)	10(0)	10(0)	$-0.30 \sim 0.24$

† Figures in parentheses indicate the number of data for $\Delta H_i < 0$.

Table 2. Breakdown list of the number of data exhibiting $\Delta p/p > 0.1$†

d (mm)	G (kg m^{-2} s^{-1})	l/d 50	100	200	400	600	800
3	4844			4(4)	12(0)	8(0)	11(0)
3	6055		6(6)	16(11)	9(0)	8(0)	5(0)
8	3060					6(0)	10(0)

† Figures in parentheses indicate the number of data for $\Delta H_i < 0$.

$\psi_k = (G^2 d/\sigma\rho_l)^{1/2}$. Then, utilizing the form of equation (2) as it is, the present data with $\Delta H_i < 0$ are analyzed to give Fig. 3(a), where ρ_l/ρ_v is a constant of 13.6 ($= 1/0.0735$). It will be noticed in Fig. 3(a) that the correlation of q_c data changes in character being affected by the tube diameter d, and that even if d is fixed, the data corresponding to a definite value of ψ_k scatter to some extent. Figure 3(b), which is similar to Fig. 3(a) but with symbols of discriminating data groups of different l/d ratios from each other, shows that the scattering in Fig. 3(a) is caused by the difference of l/d.

3.2. *Correlation of q_c/GH_{fg} vs χ_{ex} ($\Delta H_i > 0$)*

If experimental data for $\Delta H_i > 0$ are correlated in the same manner as that of Fig. 3(a), Fig. 4 is obtained. In this case, it is noticed that equation (2) holds fairly well under the condition of fixed d over a wide range of l/d between 50 and 800. In other words, q_c can now be regarded as a function of χ_{ex} alone under fixed p, d and G; and it may be of interest to add that this trend is also observed for the data of refs. [2, 3, 6, 7].

Meanwhile, Groeneveld *et al.*'s table [16], which is qualified for CHF at $d = 8$ mm, has difficulty in predicting middle values by interpolation; accord-

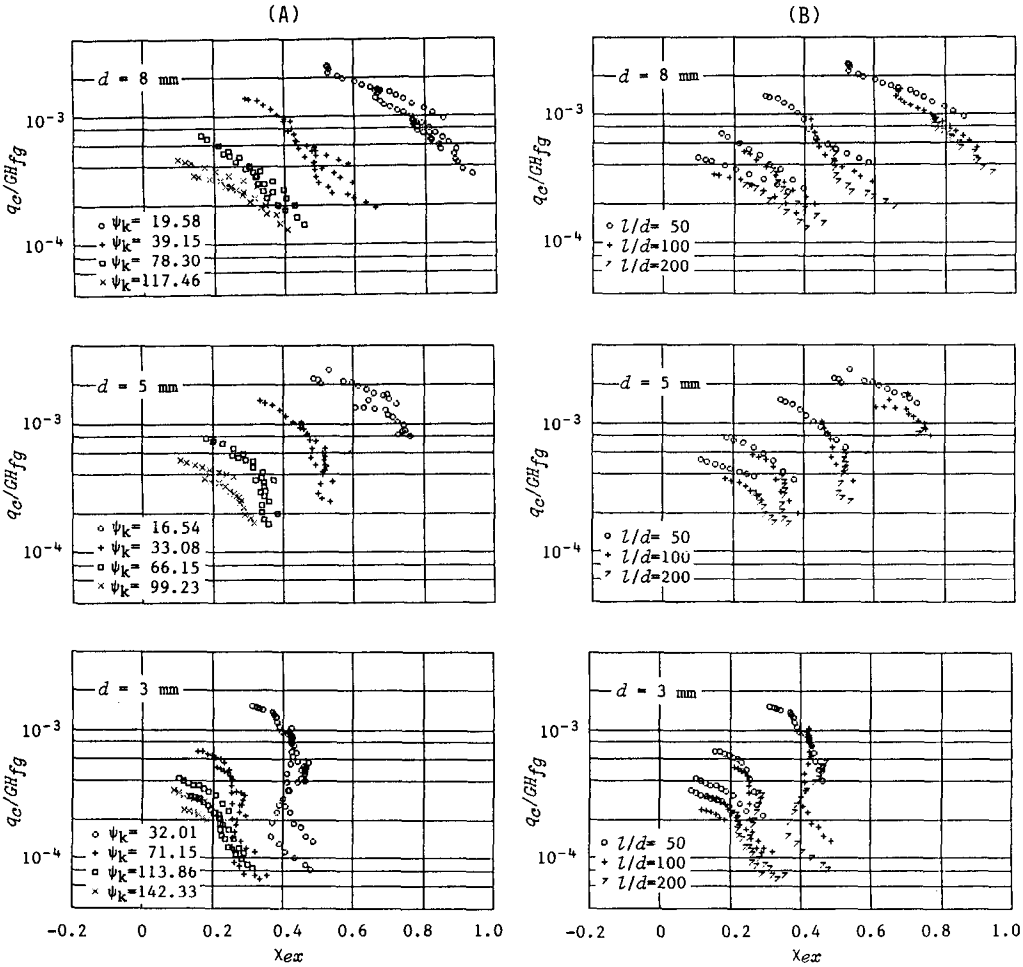

FIG. 3. Correlation of experimental data for $\Delta H_i < 0$ (R-12, $\rho_l/\rho_v = 1/0.0735 = 13.6$; $l/d = 50$, 100 and 200).

ingly, ψ_k and ρ_l/ρ_v values close to those in Fig. 4 are chosen from Groeneveld *et al.*'s table resulting in Fig. 5. It will be noticed that the characteristics of CHF in Fig. 5 are rather close to those in the top diagram of Fig. 4. However, the middle and bottom diagrams of Fig. 4 clearly suffer from the effect of d on CHF characteristics, which is particularly noticeable under the condition of high l/d values. As for the rather complicated aspect in the shape of the q_c/GH_{fg} vs χ_{ex} curves in the foregoing two diagrams, it may presumably be related to the fact that χ_{ex} is not a variable independent of q_c, as has been pointed out by one of the authors [17].

Finally, comparison between Figs. 3(a) and 4 indicates that, even in the case of such a simple preheater structure as that of Fig. 1, the expedient method of substituting CHF data of low l/d values with $\Delta H_i < 0$ (Fig. 3(a)) for those of high l/d values with $\Delta H_i > 0$ (Fig. 4) is defective in many aspects.

3.3. *CHF under saturated inlet condition* ($\Delta H_i = 0$)

As can be seen in Fig. 2, the critical heat flux value q_{c0} for $\Delta H_i = 0$ can be readily determined from each group of experimental data for a set of d, G and l/d. Figure 6 represents examples of q_{c0} values thus obtained together with prediction curves by the generalized correlation of Katto and Ohno [14] for q_{c0}

$$\frac{q_{c0}}{GH_{fg}} = f\left(\frac{\sigma\rho_l}{G^2 l}, \frac{\rho_v}{\rho_l}, \frac{l}{d}\right) \tag{3}$$

where $\sigma\rho_l/G^2 l$ is a dimensionless group, which is different from ψ_k of equation (2) in using tube length l instead of tube diameter d. To be concrete, q_{c0}/GH_{fg} is predicted by the minimum value of q_{c0}/GH_{fg} given by the following three equations:

$$\left.\begin{aligned}
\frac{q_{c0}}{GH_{fg}} &= C\left(\frac{\sigma\rho_l}{G^2 l}\right)^{0.043}\frac{1}{l/d} \\
\frac{q_{c0}}{GH_{fg}} &= 0.10\left(\frac{\rho_v}{\rho_l}\right)^{0.133}\left(\frac{\sigma\rho_l}{G^2 l}\right)^{1/3}\frac{1}{1+0.0031 l/d} \\
\frac{q_{c0}}{GH_{fg}} &= 0.098\left(\frac{\rho_v}{\rho_l}\right)^{0.133}\left(\frac{\sigma\rho_l}{G^2 l}\right)^{0.433}\frac{(l/d)^{0.27}}{1+0.0031 l/d}
\end{aligned}\right\} \tag{4}$$

where $C = 0.25$ for $l/d < 50$, $C = 0.25 + 0.0009$

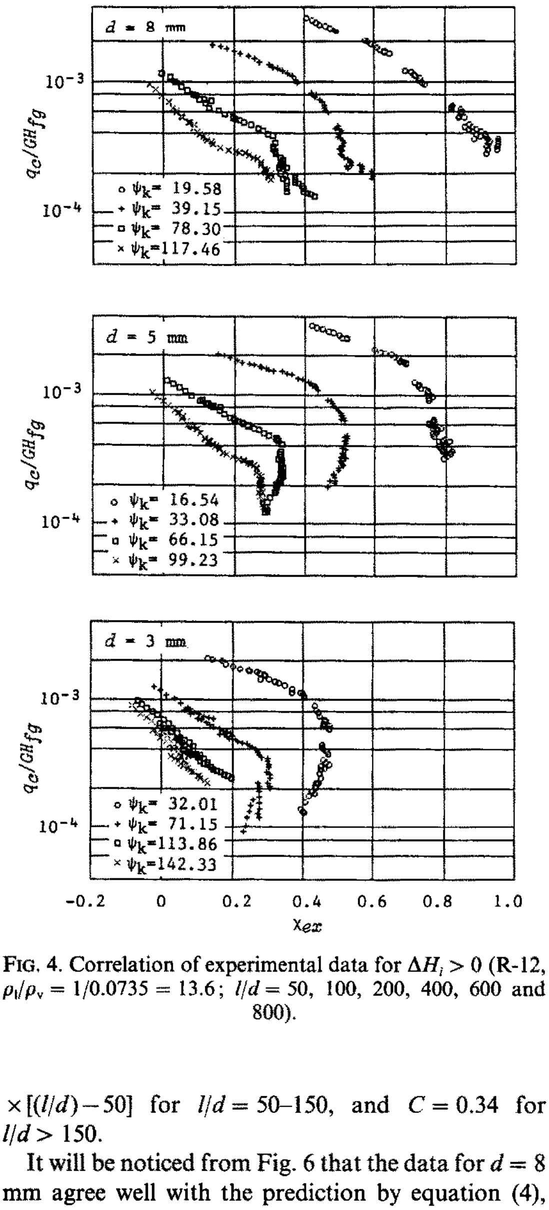

FIG. 4. Correlation of experimental data for $\Delta H_i > 0$ (R-12, $\rho_l/\rho_v = 1/0.0735 = 13.6$; $l/d = 50$, 100, 200, 400, 600 and 800).

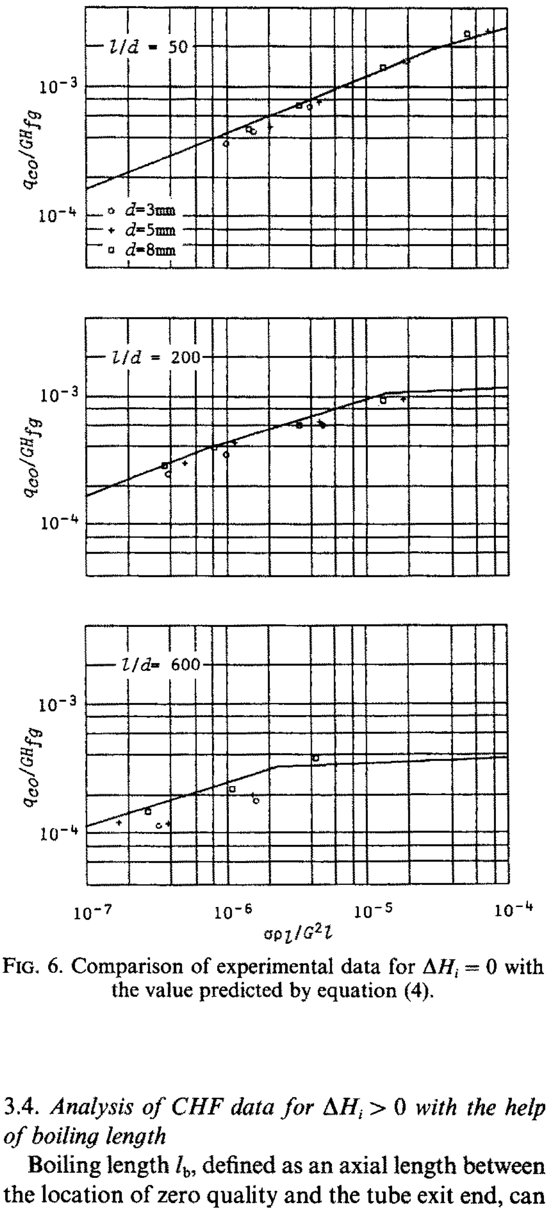

FIG. 6. Comparison of experimental data for $\Delta H_i = 0$ with the value predicted by equation (4).

$\times[(l/d)-50]$ for $l/d = 50$–150, and $C = 0.34$ for $l/d > 150$.

It will be noticed from Fig. 6 that the data for $d = 8$ mm agree well with the prediction by equation (4), while the data for $d = 5$ and 3 mm decreases from the predicted value more and more as the l/d ratio increases.

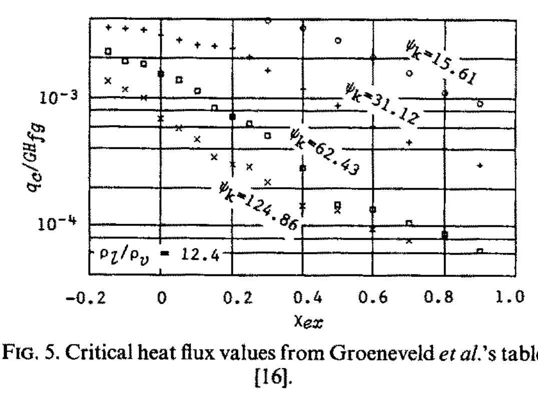

FIG. 5. Critical heat flux values from Groeneveld *et al.*'s table [16].

3.4. *Analysis of CHF data for $\Delta H_i > 0$ with the help of boiling length*

Boiling length l_b, defined as an axial length between the location of zero quality and the tube exit end, can be considered in a heated tube if it is under conditions of $\Delta H_i > 0$ at the tube inlet and $\chi_{ex} > 0$ at the tube exit. When the value of l_b/d thus determined is not excessively low, the flow configuration in part of the boiling length may be regarded as nearly equal to that of a heated tube with a saturated liquid inlet condition $\Delta H_i = 0$. Hence, all the experimental data of q_c for $\Delta H_i > 0$ excepting those of $l_b/d < 50$ are compared with the value calculated by equation (4) (where q_{c0} and l are replaced by q_c and l_b, respectively), giving rise to the results of Fig. 7. Throughout the three diagrams of Fig. 7, two different symbols have been employed to discriminate the data for $l_b/d < 400$ from those for $l_b/d > 400$ for reference.

It will be noted in Fig. 7 that the data for $d = 8$ mm agree fairly well with the prediction by equation (4), while the data for $d = 5$ and 3 mm deviate from standard values predicted by equation (4) with the same trend as that of Fig. 6. One can then draw the fol-

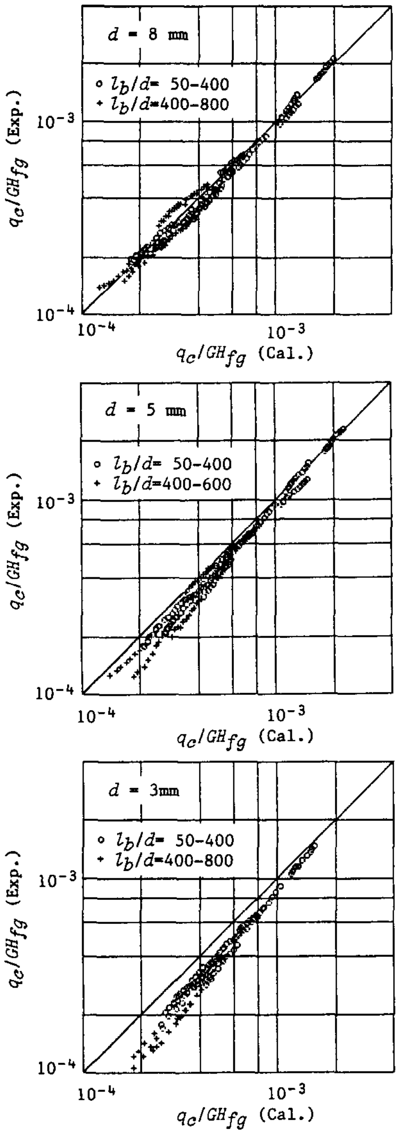

FIG. 7. Comparison of experimental data for $\Delta H_i > 0$ with the value predicted by equation (4) (R-12, $\rho_v/\rho_l = 0.0735$).

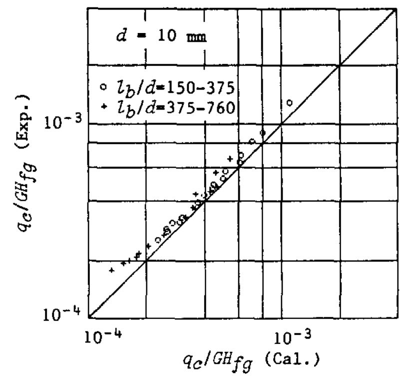

FIG. 8. Comparison of experimental data of Wurtz [6] for $\Delta H_i > 0$ with the value predicted by equation (4) (water, $\rho_v/\rho_l = 0.0494$).

lowing conclusions from the results of Figs. 6 and 7 that (i) with the help of boiling length l_b, equation (4) is useful as a means to predict CHF for $\Delta H_i > 0$ and $\chi_{ex} > 0$ up to the region of very high l_b/d ratios, and that (ii) Fig. 7 gives a tentative means to estimate the deviation of CHF from the value predicted by equation (4) for tubes of d as small as 3 or 5 mm and high l_b/d ratios.

3.5. *A check on the character of CHF for $d > 8$ mm*

The CHF data of R-12 dealt with so far in this study do not include the data for $d > 8$ mm, but fortunately, there are existing data for $d = 10$ mm obtained by Wurtz [6] with water at 7.0 MPa ($\rho_v/\rho_l = 0.0494$). The pressure drop Δp through the test tube at CHF is unknown for the Wurtz data, but the system pressure $p = 7.0$ MPa is 4.76 times higher than that of the present R-12 data, so that $\Delta p/p$ may presumably be sufficiently low within the experimental range. Figure 8 represents a comparison of the Wurtz data with the prediction of equation (4) in the same manner as that of Fig. 7. According to a previous study made by one of the authors [18], the trend is obviously observed that experimental data of q_{c0} are slightly higher than the value of q_{c0} predicted by equation (4) for water, while slightly lower than the prediction of equation (4) for R-12. Hence, if this trend is taken into account, the result of Fig. 8 may be considered as having nearly the same feature as that of the top diagram of Fig. 7; in other words, there may probably be no noticeable difference of CHF character between $d = 8$ and 10 mm in the region of high l/d ratios.

4. STUDY ON THE EFFECT OF VISCOSITY

The results of Figs. 4 and 7 have shown that, when d is as small as 3 or 5 mm and the value of l/d is high, experimental CHF data deviate from standard values predicted by either the Groeneveld or the Katto generalized correlation. In connection with this problem, it is noticed that the effect of fluid viscosity has been omitted in the foregoing two correlations (see equations (2) and (3)), so that a question may possibly arise whether the above-mentioned deviation is mainly caused by the effect of viscosity.

Hence, analytical calculations of critical heat flux q_{c0} for the saturated inlet condition, including the effect of fluid viscosity, have been conducted with an existing annular flow model [19], which postulates that liquid film flow along the wall is subject to the change of state due to the evaporation of liquid as well as the droplet exchange between the liquid film flow and the core vapor flow. The model mentioned above is the one presented by Levy *et al.* [20] and later modified by one of the authors [19] for the initial thickness of the liquid film at the starting point of annular flow in tubes of low l/d ratios, by taking into account the critical liquid film thickness concept [21].

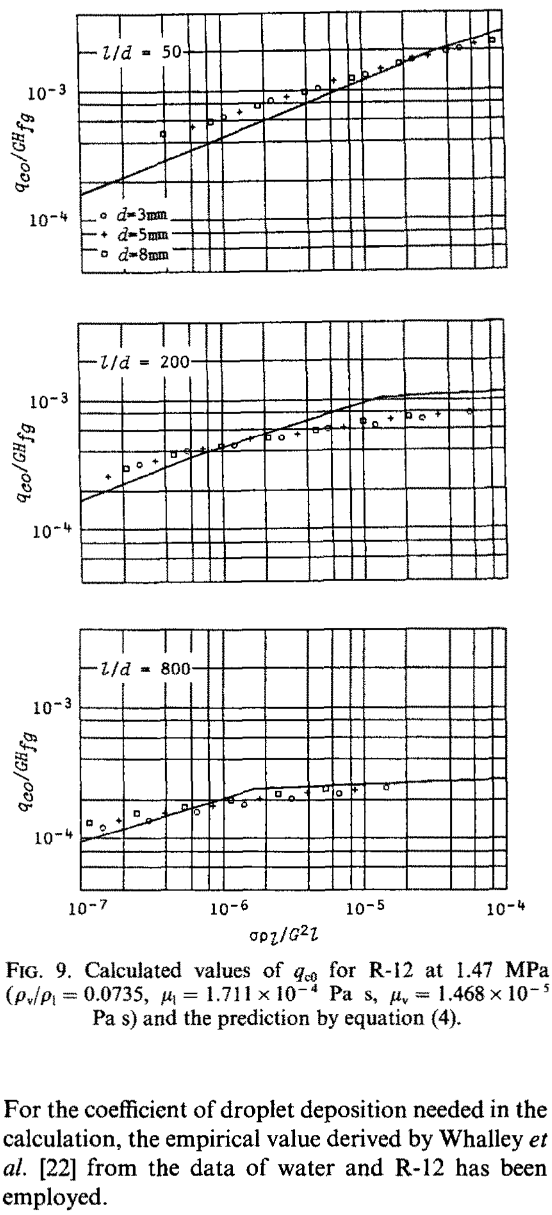

FIG. 9. Calculated values of q_{c0} for R-12 at 1.47 MPa ($\rho_v/\rho_l = 0.0735$, $\mu_l = 1.711 \times 10^{-4}$ Pa s, $\mu_v = 1.468 \times 10^{-5}$ Pa s) and the prediction by equation (4).

For the coefficient of droplet deposition needed in the calculation, the empirical value derived by Whalley *et al.* [22] from the data of water and R-12 has been employed.

Some of the q_{c0} values thus calculated with a computer for R-12 at 1.47 MPa are represented in Fig. 9 together with predicted curves from equation (4). Apart from the problem that calculated values of q_{c0} are somewhat different from the predicted curves of equation (4) (see Fig. 6 for the predictive accuracy of equation (4)), it will be noticed for the magnitudes of q_{c0} calculated for three different values of $d = 3$, 5 and 8 mm, respectively, that no substantial difference exists between them at $l/d = 50$, and a slight difference is found at $l/d = 800$, but it is too small to be compared with the difference observed in experimental data (cf. Fig. 6, though the case of $l/d = 800$ has been omitted to save space).

Of course, the foregoing calculation is not of absolute perfection in theoretical aspects. Hence, it may be dangerous to draw a conclusion from the results of Fig. 9 alone that the deviation phenomenon in Figs. 4 and 7 is independent of fluid viscosity. However, one cannot neglect the fact that the foregoing calculation strongly suggests the need for giving consideration to other factors rather than fluid viscosity, which is the problem to be solved in the future.

5. CONCLUSIONS

Experimental CHF data of R-12 at 1.47 MPa ($\rho_v/\rho_l = 0.0735$) collected over the ranges of d, G and l/d listed in Table 1 have been analyzed, from which the following conclusions are drawn.

(1) CHF data for tubes of low l/d ratios with $\Delta H_i < 0$ are undoubtedly defective in generality. Accordingly, if the q_c vs χ_{ex} correlation of such data is adopted, for example, to study CHF mechanism, it may possibly lead us to a false idea about CHF mechanism.

(2) CHF data for $\Delta H_i > 0$ correlated in the form of Fig. 4 agree fairly well with the Groeneveld correlation when $d = 8$ mm. However, if d is as small as 3 or 5 mm, the data tend to deviate from the Groeneveld correlation in the region of high l/d ratios.

(3) CHF data correlation in the form of Fig. 4 assumes a rather complicated aspect in the shape of the correlation curve, accordingly, a very sophisticated process may probably be needed if one wants to evaluate the deviation from standard CHF that has been mentioned in the preceding item.

(4) CHF data for $\Delta H_i > 0$ correlated in the form of Figs. 7 and 8 show fairly good agreement with the Katto correlation when $d = 8$ or 10 mm. However, if d is as small as 3 or 5 mm, the data deviate from the Katto correlation in the region of high l/d ratios.

(5) The results of Fig. 7 provide us with a tentative means to evaluate the deviation from standard CHF that has been mentioned in the preceding item.

(6) In connection with the deviation phenomenon appearing when d is as small as 3 or 5 mm and the value of l/d is high, analytical prediction of CHF including the effect of fluid viscosity has been attempted with an existing annular flow model. However, it has reached a result that deviations of such magnitudes as those exhibited by experimental data cannot be predicted.

Acknowledgement—The Ministry of Education, Science and Culture is acknowledged for the financial support of this study under Grant in Aid of Special Project Research for Effective Use of Thermal Energy (1984–1986).

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FLUX THERMIQUE CRITIQUE D'EBULLITION EN CONVECTION FORCEE DANS DES TUBES VERTICAUX UNIFORMEMENT CHAUFFES, POUR DES GRANDS RAPPORTS LONGUEURS/DIAMETRE

Résumé—Pour un large domaine de rapport longueur/diamètre l/d entre 50 et 800, le flux thermique critique CHF dans les tubes est étudié en considérant 1051 données de CHF qui ont été récemment obtenues avec R-12 à 1,47 MPa pour des diamètres $d = 3$, 5 et 8 mm et des débits masses spécifiques $G = 510$–6055 kg m^{-2} s^{-1}. Tout d'abord on constate l'inéquation de la méthode qui substitue les données du CHF dans les tubes avec des faibles valeurs de l/d et des enthalpies de sous-refroidissement $\Delta H_i < 0$, aux donneés relatives avec de grandes valeurs l/d et $\Delta H_i > 0$. Ensuite les CHF avec $\Delta H_i > 0$ sont analysés sur la base de deux espèces typiques de deux corrélations générales de CHF, montrant que la valeur CHF pour des tubes de diamètre aussi petit que 3 ou 5 mm tend à s'écarter des valeurs standard prédites par des corrélations généralisées précédentes basées sur les données de CHF pour l/d inférieur à 370. On propose des moyens de prédire la zone de séparation entre tubes longs et tubes courts.

KRITISCHE WÄRMESTROMDICHTE BEIM STRÖMUNGSSIEDEN IN GLEICHFÖRMIG BEHEIZTEN VERTIKALEN ROHREN UNTER BESONDERER BERÜCKSICHTIGUNG SEHR GROSSER LÄNGEN-DURCHMESSER-VERHÄLTNISSE

Zusammenfassung—Über einen weiten Bereich des Längen-Durchmesser-Verhältnisses l/d (von 50 bis 800) wurde die kritische Wärmestromdichte (CHF) in Rohren durch die Analyse von 1051 CHF-Daten untersucht, welche Experimente mit R12 bei 1,47 MPa für Rohrdurchmesser $d = 3$, 5 und 8 mm und Massenstromdichten $G = 510$ bis 6055 kg m^{-2} s^{-1} enthalten. Die Methode, CHF-Daten für Rohre mit großem l/d bei einer Unterkühlung $\Delta H_i > 0$ durch solche mit kleinem l/d bei $\Delta H_i < 0$ zu substituieren, erweist sich als untauglich. Die CHF-Daten mit $\Delta H_i > 0$ wurden auf der Grundlage von zwei typischen, existierenden allgemeingültigen Korrelationen analysiert. Man erkennt, daß der CHF-Wert für Rohrdurchmesser 3 oder 5 mm von den Standardwerten abweicht. Diese werden nach den allgemeingültigen Korrelationen berechnet, welche auf den CHF-Daten für $l/d < 370$ basieren. Die Abweichung bei langen und dünnen Rohren wird ansatzweise gedeutet.

КРИТИЧЕСКИЙ ТЕПЛОВОЙ ПОТОК ПРИ ВЫНУЖДЕННОМ КОНВЕКТИВНОМ ТЕЧЕНИИ В РАВНОМЕРНО НАГРЕВАЕМЫХ ВЕРТИКАЛЬНЫХ ТРУБАХ ДЛЯ ОЧЕНЬ БОЛЬШИХ ОТНОШЕНИЙ ДЛИНЫ ТРУБЫ К ДИАМЕТРУ

Аннотация—В широком диапазоне изменения отношений длины трубы к диаметру (от 50 до 800) систематически исследовалось влияние величины критического теплового потока (КТП) в трубах вплоть до значений 1051, которые были недавно получены в экспериментах с R-12 при 1,47 МПа для диаметра трубы $d = 3$, 5 и 8 мм, соответственно, и удельных массовых расходов $G = 510$–6055 кг м$^{-2}$ с$^{-1}$. Полученные данные указывают на непригодность подхода, в котором результаты по КТП в трубах с малыми значениями l/d для энтальпии при недогреве заменяются данными по трубам с большими значениями l/d при $\Delta H_i > 0$. Сопоставление результатов по КТП при $\Delta H_i > 0$ двумя существующими обобщенными критериальными зависимостями для расчета КТП, показывало, что величины КТП для труб диаметром от 3 до 5 мм отклоняются от значений, рассчитанных с использованием вышеуказанных обобщенных зависимостей, основанный на данных по критическому тепловому потоку для l/d, меньших, чем 370. Представлен также приближенный способ расчета вышеописанного отклонения, характерного для длинных и узких труб.