A CATALOGUE OF BURNOUT CORRELATIONS
FOR FORCED CONVECTION IN THE QUALITY REGION

by

G.C. CLERICI(*), S. GARRIBA(**), R. SALA(*) and A. TOZZI(*)

(*) ARS, SpA
(**) CESNEF

1966

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Printed by Van Muysewinkel s.p.r.l., Brussels, December 1966

This document was reproduced on the basis of the best available copy.
This report lists burnout correlations for the quality region and presents a first comparison between them. The report has been subdivided in three parts:

**Part 1 “Original Form”:** The correlations are listed in their original form, using the same symbols and units of the authors. Conditions for application...
include the geometry (circular, rectangular, or annular ducts, single channels or cluster of rods) and type of heat flux distribution (uniform or nonuniform).

Part 2 "Standard Form": has been limited to the uniform heat flux distribution and to the simplest geometries, i.e. single channels of circular, rectangular, or annular cross section.

All correlations have been rewritten in a standard form:

$$\varphi_0 = \varphi_0 (X_0)$$

where $\varphi_0$ is the burnout heat flux, $X_0$ the burnout steam quality at the outlet. Symbols and units have been standardized.

For each correlation the range of validity of the most important parameters $(G, P, D, L, L/D, X_0, X_1, \varphi_0)$ has been given.

Part 3: a first comparison of the correlations for uniform heat flux distribution and round ducts is given. All the correlations have a common range of validity.

The parameters were examined for the following ranges:

- $17.5 < P < 140$ atm
- $50 < G < 700$ g/cm² sec
- $0.2 < D < 2.5$ cm
- $20 < L < 250$ cm.
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Summary

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$$a_b = \phi (X_0)$$

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Prof. M. Silvestri gave his time generously to discuss the program during the course of the investigation.

Dr. R. Morin, Prof. H. S. Isbin and Prof. S. Albertoni provided encouragement and suggestions in the writing of this report.
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This report lists burnout correlations for the quality region and presents a first comparison between them. The report has been subdivided in three parts:

In part 1, "Original Form", the correlations are listed in their original form, using the same symbols and units of the authors. Conditions for application include the geometry - circular rectangular, or annular ducts, single channels or cluster of rods - and type of heat flux distribution - uniform or nonuniform.

In part 2, "Standard Form", we have restricted our attention to the uniform heat flux distribution and to the simplest geometries, i.e. single channels of circular, rectangular, or annular cross section.

All correlations have been rewritten in a standard form:

$$\phi = \phi_e(X_e)$$

where $\phi$ is the burnout heat flux, $X_e$ the burnout steam quality at the outlet. Symbols and units have been standardized and are reported in the Table I.

For each correlation the range of validity of the most important parameters ($G, P, D, L, L/D, X_o, X_{in}, \phi$) has been given.

(*) Manuscript received on October 20, 1966
When it was not explicitly pointed out by the authors, the range of validity was obtained by means of analysis of the experimental data used by the authors to prove or compare their correlations. This given range of validity represents the minimal and the maximal values which the single parameters may assume. The possible coupling between parameters has yet to be determined. For example, without specific details, the correlations may not be valid for the maximal flow rate and the minimal diameter.

Some information about the asymptotic trends, namely
\[ \lim \phi_0(X \to 0), \lim \phi_0(X \to 1), \lim \phi_0(P \to P_m), \lim \phi_0(G \to G), \lim \phi_0(G \to G) \]
is reported as items of interest, but not necessarily as valid points of the correlation. The applicable ranges for the correlations have been summarized in the Table II, and are compared in the Figures 1-6.

In part 3, a first comparison of the correlations for uniform heat flux distribution and round ducts is given. All the correlations have a common range of validity.

For our comparison, we have chosen the common point:
\[ P=72 \text{ ata}, \ G=219 \text{ gr/cm}^2 \text{ sec}, \ D=0.918 \text{ cm}, \ L=139.9 \text{ cm}. \]
In the figures 7-9, we have reported the critical heat flux versus outlet quality, for \( X_{in} = 0 \) and three parameters of the set \( P, G, D, L \) are fixed, plots of \( \phi_0 \) versus the free parameter are gi-
ven in Figures (10-21), with $\phi_0$ vs. $P$ in Figures (11-15), $\phi_0$ vs. $L$ in Figures (16-18), and $\phi_0$ vs. $D$ in figures (19-21).

The parameters were examined for the following ranges:

$17.5 \leq P \leq 140$ ata  $50 \leq G \leq 700$ gr/cm$^2$ sec  $0.2 \leq D \leq 2.5$ cm

$20 \leq L \leq 250$ cm.

For each correlation the trend of $\phi_0$ was given through the whole chosen range, without care to the validity range; however this range was marked on the same diagrams. Where tables or figures were used in the original presentation to denote dependency upon pressure or upon some other physical parameters, we have employed an analytical approximation determined by a linear regression program. For these cases, the plots are further limited by the validity of the analytical approximation.

* 

In this case the range of validity will be indicated as:

Probably Range of Validity
PART 1

ORIGINAL FORM
The correlation, given for an uniform heat flux distribution and for round and rectangular channels, has the following form

\[ W_B e^n = \frac{K' \lambda}{D^{0.25}} \frac{100 - X}{X + a} \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
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<tbody>
<tr>
<td>( W_B )</td>
<td>Burnout Heat Flux</td>
<td>(10^6) Btu/ft(^2) - hour</td>
</tr>
<tr>
<td>( G )</td>
<td>Mass velocity</td>
<td>(10^6) lb/ft(^2) - hour</td>
</tr>
<tr>
<td>( D )</td>
<td>Hydraulic Equivalent Diameter</td>
<td>in.</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Latent Heat of vaporization</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>( X )</td>
<td>Burnout Steam Quality</td>
<td>dimensionless</td>
</tr>
<tr>
<td>( a )</td>
<td>Ratio between specific volume of liquid and specific volume change upon vaporization</td>
<td>dimensionless</td>
</tr>
<tr>
<td>( V_f )</td>
<td>Specific volume of liquid</td>
<td>ft(^3)/lb</td>
</tr>
<tr>
<td>( V_{gf} )</td>
<td>Specific volume change upon vaporization</td>
<td>ft(^3)/lb</td>
</tr>
<tr>
<td>( K' )</td>
<td>Pressure dependent constant</td>
<td>(p.s.i.a.)</td>
</tr>
<tr>
<td>( n )</td>
<td>Pressure dependent constant</td>
<td>(p.s.i.a.)</td>
</tr>
</tbody>
</table>

\( k' = k'(P) \) and \( n = n(P) \) can be obtained by means of the two diagrams of the fig. 14 and 15 - page 649 - in the above mentioned reference.
The correlation, given for an uniform and non-uniform heat flux distribution, for round, rectangular and annular channels, has the following form (saturated boiling):

\[ K_{cr} = \frac{1.9 \times 10^{-5} \cdot Re}{1 + 1.8 \times 10^{6} \frac{Re}{K} \left( K_3 + K_4 \right)} \]

where \( K_{cr} \), \( Re \), \( K_3 \), \( K_4 \) are the following dimensionless groups:

\[ K_{cr} = \frac{q_{cr}}{r(1-x)(g \gamma''\gamma''')^{1/2} \left[ \delta(\gamma' - \gamma'') \right]^{1/4}} \]

\[ Re = \frac{W}{\gamma'^3} \left( \frac{\delta}{\gamma' - \gamma''} \right)^{1/2} \]

when \( D \gg \left( \frac{6}{\gamma' - \gamma''} \right)^{1/4} \)

\[ Re = \frac{WD}{\gamma''} \]

when \( D \ll \left( \frac{6}{\gamma' - \gamma''} \right)^{1/4} \)
\[ l_1 \left( \frac{\delta' - \delta''}{6} \right) = k_3^* \quad \text{when } k_3^* \leq 50 \]

\[ K_3 = \]

\[ 50 \quad \text{when } K_3 > 50 \]

\[ \frac{l_2}{d_4} = k_4^* \quad \text{when } k_4^* \leq 125 \]

\[ K_4 = \]

\[ 125 \quad \text{when } K_4 > 125 \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
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</thead>
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<tr>
<td>( q_{cr} )</td>
<td>Burnout Heat Flux</td>
<td>kcal/m^2·hour</td>
</tr>
<tr>
<td>( r )</td>
<td>Latent heat of vaporization</td>
<td>kcal/kg</td>
</tr>
<tr>
<td>( \chi )</td>
<td>Burnout Steam Quality</td>
<td>dimensionless</td>
</tr>
<tr>
<td>( g )</td>
<td>Gravity acceleration</td>
<td>m/h^2</td>
</tr>
<tr>
<td>( \delta', \delta'' )</td>
<td>Liquid and Steam specific gravity</td>
<td>kg/m^3</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Surface Tension</td>
<td>kg/m</td>
</tr>
<tr>
<td>( \nu' )</td>
<td>Kinematic viscosity of the liquid</td>
<td>m^2/h</td>
</tr>
<tr>
<td>( l_4 )</td>
<td>Distance between the section at which subcooled surface boiling begins and the section under consideration can be obtained by a further correlation</td>
<td>m</td>
</tr>
</tbody>
</table>
\( \text{w} \) \text{liquid (\( \cdot \) or flow (\( \cdot \cdot \)) velocity \text{m/h}}

\( l_2 \) \text{Distance between the section at which saturated net boiling begins and the section under consideration. \text{m}}

\( \delta \) \text{Gap for rectangular and annular channels \text{m}}

\( d_H \) \text{Hydraulic equivalent diameter \text{m}}

\[ D \begin{cases} \frac{d_H}{2} & \text{for round ducts} \\ \frac{\delta}{2} & \text{for rectangular and annular channels with bilateral heating} \\ \delta & \text{for rectangular and annular channels with unilateral heating} \end{cases} \]

(1) \text{For an uniform heat flux distribution} \quad \varphi = 1

\text{For non uniform heat flux distribution}

\[ \varphi = q/\bar{q} \quad \text{with} \quad \bar{q} = \frac{1}{P} \int q \, dp \quad \text{for radial nonuniformity} \]

\( P \) \text{is the perimeter}

\[ \bar{q} = \frac{1}{b} \int q \, db \quad \text{for axial nonuniformity} \]

\( b \) \text{is the distance between the inlet section and the section in consideration}

\text{when} \quad \frac{b}{d_H} > 125 \quad \text{the integration is made between} \quad b-125 \, d_H \text{and} \quad b
The critical Heat Flux for boiling water in tubes
Atomnaya Energiya - Vol. II, No. 6, pages 515-521 December 1961

Z. H. Miropol'skii - L. E. Faktorovich : General conclusions derived from experimental results on the influence of the Heated length of a channel on the critical Heat Flux
Soviet Physics Doklady Vol. 6 N. 12 pag. 1058-1061 June 1962

The correlation, given for an uniform heat flux distribution, for round, rectangular channels and for annuli with bilateral heating, has the following form:
\[
\frac{q_{cr}}{6} = c_1 \left( \frac{c_p T_s}{r} \right)^{0.8} K_{W}^{0.4} (1 - \chi)^n
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
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<tr>
<td>( q_{cr} )</td>
<td>Burnout Heat Flux</td>
<td>kcal/m(^2)-hour</td>
</tr>
<tr>
<td>( \mu )</td>
<td>Liquid absolute viscosity</td>
<td>kg-sec /m(^2)</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Surface Tension</td>
<td>kg/m</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>Liquid Density at (T_{sat})</td>
<td>kg/m(^3)</td>
</tr>
<tr>
<td>( r )</td>
<td>Latent heat of vaporization</td>
<td>kcal/kg</td>
</tr>
<tr>
<td>( c_1 )</td>
<td>Constant dependent on the Geometry (1)</td>
<td></td>
</tr>
<tr>
<td>( T_s )</td>
<td>Saturation Temperature</td>
<td>°K</td>
</tr>
<tr>
<td>( K_W )</td>
<td>Constant dependent on the pressure, mass velocity (2)</td>
<td>dimensionless</td>
</tr>
<tr>
<td>( \chi )</td>
<td>Burnout Steam Quality</td>
<td>dimensionless</td>
</tr>
<tr>
<td>( n )</td>
<td>Constant dependent on (K_W) (3)</td>
<td></td>
</tr>
<tr>
<td>( W_g )</td>
<td>Mass velocity</td>
<td>kg/m(^2)-sec</td>
</tr>
<tr>
<td>( c_p )</td>
<td>Liquid specific heat</td>
<td>kcal/kg-°C</td>
</tr>
</tbody>
</table>
(1) $c_1$ is a constant dependent on the geometry and on the ratio $L/D$.

(2) $K_w = \frac{w \mu'}{\delta'} \left( \frac{\delta'}{\delta''} \right)^{0.2}$

(3) For round ducts and annular channels: $n = 0.8$ if $k_w < 1.6 \times 10^{-2}$; $n = 50 k_w$ if $1.6 \times 10^{-2} \leq k_w \leq 6.1\times 10^{-2}$; $n = 3$ if $k_w > 6.1 \times 10^{-2}$.

For rectangular channels: $n = 33.3 k_w$ if $2.1 \times 10^{-2} \leq k_w \leq 9.1 \times 10^{-2}$; $n = 3$ if $k_w > 9.1 \times 10^{-2}$.

\[ C_1 \begin{cases} 0.174 & \text{when } L/D > 100 \\ 0.174 c_1^* & \text{when } L/D < 100 \end{cases} \]

\[ C_1 \begin{cases} 0.224 & \text{when } L/D > 100 \\ 0.224 c_1^* & \text{when } L/D < 100 \end{cases} \]

and where $c_1^*$ is the smaller value between $e^{0.0122(100 - L/D)}$ and $0.373 \left[ \frac{w \mu'}{\delta'} \left( \frac{\delta'}{\delta''} \right)^{0.2} (1-x)^{2.5n} \right]^{-0.4}$. 

10
Prediction of the critical Heat Flow in Forced convection
Flow - GEAP 3961 June 1962

The correlation, given for uniform and non uniform heat flux
distribution, for round tubes, rectangular channels and annuli
heated on one or both sides, has the following form:

$$\left( \frac{q}{A} \right)_p + \left( \frac{q}{A} \right)_F + \left( \frac{q}{A} \right)_M = 0.131 \ h_{fg} \ \rho_f \ \rho_v \ \left( \frac{6 \ \gamma^2 (\rho_l - \rho_v)}{\rho_v^2} \right)^{1/4} + h_L \ \left( T_w - T_s \right) + h_{fg} \ \Delta T \ \cdot \ M_v$$

with

$$M_v = \frac{C \ \rho_L \ \frac{K^2 \ \beta^2}{1 - \beta_v^2 \ \beta_l}}{G}$$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\left( \frac{q}{A} \right)_p$</td>
<td>Burnout Heat Flux for the pool boiling</td>
<td>Btu/hour</td>
</tr>
<tr>
<td>$\left( \frac{q}{A} \right)_F$</td>
<td>Burnout Heat Flux for the Forced convection</td>
<td>Btu/hour</td>
</tr>
<tr>
<td>$\left( \frac{q}{A} \right)_M$</td>
<td>Burnout Heat Flux for the Mass Transfer</td>
<td>Btu/hour</td>
</tr>
<tr>
<td>$h_{fg}$</td>
<td>Latent heat of vaporization</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>$\rho_f$</td>
<td>Vapor Density</td>
<td>lb/ft$^3$</td>
</tr>
<tr>
<td>$\rho_v$</td>
<td>Surface Tension</td>
<td>lb/ft</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Gravitational Constant</td>
<td>ft/hour$^2$</td>
</tr>
<tr>
<td>$\beta_l$</td>
<td>Liquid Density</td>
<td>lb/ft$^3$</td>
</tr>
<tr>
<td>$h_L$</td>
<td>Heat transfer coefficient for the liquid</td>
<td>Btu/hour-ft$^{-2}$-°F</td>
</tr>
<tr>
<td>$T_w$</td>
<td>Wall Temperature</td>
<td>°F</td>
</tr>
<tr>
<td>$T_s$</td>
<td>Saturation Temperature</td>
<td>°F</td>
</tr>
</tbody>
</table>
\( \Delta T_{\text{sub}} \)  Subcooling  \( ^\circ F \)

\( C \)  Diffusion coefficient  \( \text{ft}^2/\text{hour} \)

\( \mu_e \)  Liquid absolute viscosity  \( \text{lb/\text{hour-ft}} \)

\( K \)  Mixing length constant

\( \beta \)  Dimensionless constant \(^{(1)}\) dependent on the Pressure and Quality

\( G \)  Mass velocity  \( \text{lb/\text{hour-ft}^2} \)

\(^{(1)}\) \( \beta \) can be obtained by the tables on pages 6 and 7 in the above mentioned references.
Experimental investigation of the condition of deterioration
of heat transfer during boiling in tubes

Teploenergetika Vol. 9, No. 8 pp. 77-81 1962
(Translated in AEC-tr-5539)

The correlation, given for an uniform heat flux distribution
and for round ducts has the following form:

\[ X_d = \left[ \frac{q}{\varpi} \sqrt{\frac{6}{\rho' \rho''}} \right]^{-0.125} Pr^{-0.5} \left( \frac{\mu'}{\mu''} \right)^{0.2} \left( \frac{d}{\sqrt{\frac{6}{\rho' \rho''}}} \right)^{0.2} \left( \frac{500}{Re \frac{d''}{\rho' \rho''}} + 350 \right) ^{0.35} \]

where \( Re = \frac{G (1 - X_{av})}{\varpi u' \gamma'} \)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_d )</td>
<td>Burnout steam quality</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>( q )</td>
<td>Burnout heat flux</td>
<td>kcal/m(^2) hr</td>
</tr>
<tr>
<td>( \varpi )</td>
<td>Latent heat of vaporization</td>
<td>kcal/kg</td>
</tr>
<tr>
<td>( \delta', \delta'' )</td>
<td>Liquid or steam density</td>
<td>kg/m(^3)</td>
</tr>
<tr>
<td>( \delta )</td>
<td>Surface tension</td>
<td>kg/m</td>
</tr>
<tr>
<td>( \gamma' )</td>
<td>Liquid kinematic viscosity</td>
<td>m(^2)/hr</td>
</tr>
<tr>
<td>( Pr_e )</td>
<td>Liquid Prandtl's number</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>( \mu', \mu'' )</td>
<td>Liquid or steam viscosity</td>
<td>kg hr/m(^2)</td>
</tr>
<tr>
<td>( d )</td>
<td>Diameter</td>
<td>m</td>
</tr>
<tr>
<td>( G )</td>
<td>Total mass flow rate</td>
<td>kg/hr</td>
</tr>
<tr>
<td>( u )</td>
<td>Perimeter</td>
<td>m</td>
</tr>
<tr>
<td>( X_{av} )</td>
<td>Not defined in the translation</td>
<td>Dimensionless</td>
</tr>
</tbody>
</table>
Critical Thermal loads During the boiling of a saturated liquid in tube. Atomnaya Energeta - Vol. 13 - No. 4 - pages 377-380 October 1962

The correlation, given for an uniform heat flux distribution, and for round ducts has the following form:

\[ K = \frac{q_{cr}}{r \sqrt{g \delta''} \sqrt{6(\delta' - \delta'')}} = K_0 \left( 1 - n \beta \right) \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_{cr} )</td>
<td>Burnout Heat Flux</td>
<td>kcal/m^2-hour</td>
</tr>
<tr>
<td>( r )</td>
<td>Latent heat of vaporization</td>
<td>kcal/kg</td>
</tr>
<tr>
<td>( g )</td>
<td>Gravity Acceleration</td>
<td>m/hour^2</td>
</tr>
<tr>
<td>( \delta' )</td>
<td>Liquid density at ( T_{sat} )</td>
<td>kg/m^3</td>
</tr>
<tr>
<td>( \delta'' )</td>
<td>Steam density at ( T_{sat} )</td>
<td>kg/m^3</td>
</tr>
<tr>
<td>( T_{sat} )</td>
<td>Saturation Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Surface Tension</td>
<td>kg/m</td>
</tr>
<tr>
<td>( K_0 )</td>
<td>Value of ( K ) when ( \beta = 0 )</td>
<td></td>
</tr>
<tr>
<td>( n )</td>
<td>Constant dependent on ( K_w )</td>
<td></td>
</tr>
<tr>
<td>( \beta )</td>
<td>Volume flow rate quality</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>( K_w )</td>
<td>Constant dependent on ( W_0 ) and ( \rho )</td>
<td></td>
</tr>
<tr>
<td>( W_0 )</td>
<td>( W_0 \cdot \delta' ) mass velocity</td>
<td></td>
</tr>
<tr>
<td>( \rho )</td>
<td>Pressure</td>
<td></td>
</tr>
</tbody>
</table>

(1) \[ n = 0.08 K_w^{0.55} \]
(2) when $14 \leq Kw \leq 50 \quad K_o = 0.0575 \quad Kw^{0.25}$

when $50 \leq Kw \leq 80 \quad K_o = 0.0145 \quad Kw^{0.6}$

(3) $K_w = W_o \sqrt[4]{\frac{3-2x}{3^{3}5}}$
M. Silvestri et al.

A Research program in two-phase flow: work performed under the Euratom contract N. 002-II RDI C CAN-I) January 1963

The correlation, given for an uniform heat flux distribution and for round tubes (some data were taken with anular tubes for a fixed pressure, 70 ata, and external heating only) has the following form

\[ \Phi_{\text{m}} = \frac{1 - X_{\text{bo}}}{a + X_{\text{bo}}} K \]

### Symbol

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Phi_{\text{bo}} )</td>
<td>Burnout Heat Flux</td>
<td>watt/cm^2</td>
</tr>
<tr>
<td>( G )</td>
<td>Mass velocity</td>
<td>g/cm^2 sec</td>
</tr>
<tr>
<td>( D )</td>
<td>Hydraulic Equivalent Diameter</td>
<td>cm</td>
</tr>
<tr>
<td>( L )</td>
<td>Channel length</td>
<td>cm</td>
</tr>
<tr>
<td>( X_{\text{bo}} )</td>
<td>Burnout Steam Quality</td>
<td>Dimensionless number %</td>
</tr>
<tr>
<td>( a )</td>
<td>Ratio between specific volume of liquid and specific volume change upon vaporization: ( V_l/V_{gl} )</td>
<td>Dimensionless number %</td>
</tr>
<tr>
<td>( V_l )</td>
<td>Specific Volume of liquid</td>
<td>cm^3/g</td>
</tr>
<tr>
<td>( V_{gl} )</td>
<td>Specific Volume change upon vaporization</td>
<td>cm^3/g</td>
</tr>
<tr>
<td>( K )</td>
<td>Constant dependent on pressure and ( L/D )</td>
<td>equal to ( 14150/(L/D)^{0.39} ) for ( P=70 ) ata</td>
</tr>
</tbody>
</table>

16
n Constant dependent on the Pressure
m Constant dependent on the Pressure
P Pressure

(1) For uniform and non uniform heat flux distribution similar but not equivalent correlation was adopted by Casagrande (Energia Nuclare - Vol. 10 - No. 11 - pages 571-572 November 1963) for P=70 ata

\[ \frac{1-X_{\delta_0}}{2+X_{\delta_0}} \frac{K}{(L10)^{1/3}} = 6 \phi_{\delta_0}^{1/2} \text{ with } K = 11000 \]

in the case of non uniform heat flux distribution

\[ \phi_{\delta_0} = \frac{4}{L} \int_{0}^{L} \phi \, dL \]

(2) \( m=m(p) \) and \( n=n(p) \) can be obtained by means of the two diagrams on fig. II-40 (page 185) in the above mentioned reference
D. H. Lee - J. D. Obertelli

An Experimental Investigation of Forced convection Burnout in High Pressure water, AEEW-R 213 August 1963

The correlation, which is a modified form for the WAPD-188 burnout correlation at 1000 psia, is given for an uniform heat flux distribution in round tubes, and has the following form:

\[ \phi = 0.45 \left(1 + \frac{0.546}{G} \right) \left( \frac{H_{B0}}{10^3} \right)^{-2} \exp \left[ -0.00165 \frac{L}{D} \right] \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi )</td>
<td>Burnout Heat Flux</td>
<td>( 10^6 \text{ Btu/ft}^2\text{-hour} )</td>
</tr>
<tr>
<td>( G )</td>
<td>Mass Velocity</td>
<td>( 10^6 \text{ lb/ft}^2\text{-hour} )</td>
</tr>
<tr>
<td>( H_{B0} )</td>
<td>Burnout Enthalpy</td>
<td>( \text{Btu/lb} )</td>
</tr>
<tr>
<td>( D )</td>
<td>Diameter</td>
<td>( \text{in} )</td>
</tr>
<tr>
<td>( L )</td>
<td>Channel Length</td>
<td>( \text{in} )</td>
</tr>
</tbody>
</table>
Forced convection burnout in single uniformly heated channels: a detailed analysis of world data. AEEW-5892 A (1963)

There are two distinct correlations for high and low mass velocities, which have been developed for round tubes and rectangular channels heated on both sides with an uniform heat flux distribution.

1) High velocity

Round channels

\[
\Phi/10^6 = \chi_0 \frac{d}{D} \left( \frac{G}{10^6} \right)^{\gamma_1} - \frac{1}{4} \gamma_3 \frac{D}{W} \left( \frac{G}{10^6} \right)^{\gamma_5+1} \lambda W
\]

Rectangular channels with bilateral heating

\[
\Phi/10^6 = \chi_0 \frac{s}{S} \gamma_1 \left( \frac{G}{10^6} \right)^{\gamma_2} - 0.555 \gamma_3 \frac{s}{S} \left( \frac{G}{10^6} \right)^{\gamma_5+1} \lambda W
\]

2) Low velocity

Round channels

\[
\Phi/10^6 = \frac{\lambda}{135} \left( \frac{G}{10^6} \right)^{1/2} (1 - W)
\]
Rectangular channels

\[
\frac{\phi}{10^6} = \frac{\left( \frac{G}{10^6} \right) \left( \lambda + \Delta H_i \right)}{3.78 \, S^{-1.73} \left( \frac{G}{10^6} \right)^{1.1} + \frac{1.8 \, L}{S}}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\phi)</td>
<td>Burnout Heat Flux</td>
<td>Btu/ft(^2)-hour</td>
</tr>
<tr>
<td>(G)</td>
<td>Mass velocity</td>
<td>lb/ft(^2)-hour</td>
</tr>
<tr>
<td>(W)</td>
<td>Average mass flow rate quality</td>
<td>lb/lb</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>Latent heat of vaporization</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>(D)</td>
<td>Internal tube Diameter</td>
<td>in.</td>
</tr>
<tr>
<td>(S)</td>
<td>Internal spacing between heating surfaces of rectangular channel</td>
<td>in.</td>
</tr>
<tr>
<td>(\Delta H_i)</td>
<td>Subcooled Enthalpy at channel inlet</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>(L)</td>
<td>Channel Length</td>
<td>in.</td>
</tr>
</tbody>
</table>

The constants \(y_0, y_1, y_2, y_3, y_4, y_5\) and \(y'_0, y'_1, y'_2, y'_3, y'_4, y'_5\) are dependent on the Pressure \((P)\) and can be obtained by Tables on pages 10 and 15 in the above mentioned references.
Critical Heat Fluxes in Annular Channels

Critical Heat Fluxes in Annular Channels with Heat Supply from two sides, Inzh. Fiziki Fizikai Zhurnal - Vol 7 - No. 9 pages 30-33 September 1964

The correlation, given for an uniform unilateral heating
and for an uniform bilateral heating, for annular channels, has the following form:

\[ q_{cr} = q_o \left[ 1 + 4.41 \times 10^{-6} \left( \frac{\rho''}{\rho'} \right)^{0.73} \right] \]

where \( K_2 = \frac{i' - i_{out}}{r} \) for unilateral heating

\[ K_2 = \frac{i' - i_{out}}{r} + \frac{3.6 \times 10^3 \cdot q_f_2}{W_g r_f_1} \] for bilateral heating

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_{cr} )</td>
<td>Burnout Heat Flux</td>
<td>watt/m²</td>
</tr>
<tr>
<td>( q_o )</td>
<td>Critical heat flux at ( X = 0 )</td>
<td>watt/m²</td>
</tr>
<tr>
<td>( \rho' )</td>
<td>Liquid density at ( T_{sat} )</td>
<td>kg/m³</td>
</tr>
<tr>
<td>( \rho'' )</td>
<td>Steam density at ( T_{sat} )</td>
<td>kg/m³</td>
</tr>
<tr>
<td>( i' )</td>
<td>Saturation Enthalphy</td>
<td>kcal/kg</td>
</tr>
</tbody>
</table>
\( t_{\text{our}} \)  
Outlet Enthalpy  
\( \text{Kcal/kg} \)

\( r \)  
Latent heat of vaporization  
\( \text{Kcal/kg} \)

\( q \)  
Specific heat flux from the surface at which no crisis is expected  
\( \text{watt/m}^2 \)

\( f_i \)  
Cross sectional area of channel  
\( \text{m}^2 \)

\( f_2 \)  
Area of the surface from which \( q \) is removed  
\( \text{m}^2 \)

\( W_g \)  
Mass velocity  
\( \text{kg/m}^2 \cdot \text{hour} \)

\( L \)  
Length  
\( \text{m} \)

\( (1) \)  
\( q_o = 0.611 \times 10^{-3} \times 158 - 0.262 \)
Burnout in uniformly heated round tubes: A compilation of World data with accurate correlations— AEEW-R 356

The correlation, given for an uniform heat flux distribution and for round channels, is a modified form of the previous Macbeth correlation for the high velocity regime:

\[ \phi \cdot 10^{-6} = \frac{A' - 0.25^D (G \cdot 10^{-6}) \cdot W \cdot \lambda}{C'} \]

\[ A' = y_0 D^4 (G \cdot 10^{-6})^{y_3} \left[ 1 + y_3 D + y_4 (G \cdot 10^{-6}) + y_5 D (G \cdot 10^{-6}) \right] \]

\[ C' = y_6 D^{y_3} (G \cdot 10^{-6})^{y_3} \left[ 1 + y_9 D + y_{10} (G \cdot 10^{-6}) + y_{11} D (G \cdot 10^{-6}) \right] \]

The optimal values of \( y_i \) are given in table I (page 4) of the above mentioned reference, corresponding to the four groups of pressure 560, 1000, 1550, 2000 psia.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Internal tube diameter</td>
<td>in.</td>
</tr>
<tr>
<td>G</td>
<td>Average mass velocity</td>
<td>lb/hr ft^2</td>
</tr>
<tr>
<td>W</td>
<td>Quality at position of burnou.</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>( y_0 ) to ( y_{11} )</td>
<td>Numerical values optimized by the computer</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Latent heat at system pressure</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>( \phi )</td>
<td>Burnout heat flux</td>
<td>Btu/hr ft(^2)</td>
</tr>
</tbody>
</table>
F. E. Tippets

Analysis of the critical Heat-Flux condition in High-Pressure Boiling water flows.

The correlation, given for round, rectangular and annular channels and for an uniform heat flux distribution has the following form:

\[ q_c = c'' \frac{\psi^m}{3} \]

with

\[ \psi = \frac{6 \int_e (1+\frac{p}{p_l})}{\phi_{TPF} f_{b} \left(1+\sqrt{\frac{p}{p_l}} \right)} \]

\[ 3 = \frac{1+c'(1-x_c)}{f_{g} g_{h} g_{g}} \]

\[ c'' = 2K_3 K_4 \]

Symbol | Definition | Units
---|---|---
\( q_c \) | Burnout Heat Flux | Btu/ft\(^2\)-sec
\( c' \) and \( c'' \) | Empirical constants | Dimensionless
\( m \) | Empirical constant | Dimensionless
\( \sigma \) | Surface Tension | lbm/sec\(^2\)
\( \rho_L \) | Liquid Density | lbm/ft\(^3\)
\( \rho_g \) | Vapor Density | lbm/ft\(^3\)
\( \phi_{TPF} \) | Two phase friction multiplier | Dimensionless
\( f_F \) | Fanning friction factor | Dimensionless
\( G \) | Mass Velocity | lbm/ft\(^2\)-sec.
\( b \) | Hydraulic Radius for rectangular channels and annuli. Radius for circular Tubes | ft.
\[ X_c \quad \text{Burnout Steam Quality} \]

\[ h_{fg} \quad \text{Latent heat of vaporization} \quad \text{Btu/lbm} \]

\[ K_{1,2,3,4,5,6} \quad \text{Numerical constants} \]

\[ \text{Dimensionless} \]

\[ \text{Dimensionless} \]
There are two correlations \(^{(1)}\), given for an uniform heat flux distribution and for round ducts, with the following forms:

\[
1) \quad q_{b_0} = 46.5 W_g \left(1 - x\right)^m \left(\frac{\gamma'}{\gamma''}\right)^{2.2} \left(1 + \frac{8 \cdot 10^9}{W_g K}\right) \frac{2.71}{d_m^{0.48}}
\]

\[
2) \quad q_{b_0} = \left[146 \cdot 10^{-4} n, 1.72 \left(1 - x\right)^{m'} - 0.116 W_g\right] \frac{2.71}{d_m^{0.48}}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(q_{b_0})</td>
<td>Burnout Heat Flux</td>
<td>watt/m²</td>
</tr>
<tr>
<td>(W_g)</td>
<td>Mass Velocity</td>
<td>kg/m²·h</td>
</tr>
<tr>
<td>(x)</td>
<td>Burnout Steam Quality</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>(\gamma')</td>
<td>Liquid Density at (T_{sat})</td>
<td>kg/m³</td>
</tr>
<tr>
<td>(\gamma'')</td>
<td>Steam Density at (T_{sat})</td>
<td>kg/m³</td>
</tr>
<tr>
<td>(d_m)</td>
<td>Diameter</td>
<td>mm</td>
</tr>
<tr>
<td>(n, m, m')</td>
<td>Constant dependent on the Pressure (^{(2)})</td>
<td></td>
</tr>
<tr>
<td>(K)</td>
<td>Constant dependent on the Pressure and on the Steam Quality (^{(3)})</td>
<td></td>
</tr>
<tr>
<td>(r)</td>
<td>Latent heat of vaporization</td>
<td>j/kg</td>
</tr>
</tbody>
</table>

27
(1) The first correlation is valid for high pressures (100–200 kg/cm²), the second for the pressure range: 40–100 kg/cm².

(2) \( n = 0.56 - 0.0189 \frac{\theta'}{\theta''} \quad m = 0.7 \quad m' = 3.48 - 0.54 \left( \frac{r}{4.18 \cdot 10^6} \right) \)

(3) \( K = 1.13 + 3.5 \frac{\theta''}{\theta'} - 0.45 \times \)
The correlation, given for an uniform and non uniform heat flux-distribution and for round tubes, rectangular channels, and rod bundle, has the following form:

\[
H_\text{bsb} - H_\text{in} = 0.529 (H_\text{f} - H_\text{in}) + H_{tg} \left\{ (0.825 + 2.36 e^{-17D_e}) e^{-15G/10} - 0.41 G - 0.048L/10 \right\}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_{bsb}</td>
<td>Burnout Enthalpy</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>H_{in}</td>
<td>Inlet Enthalpy</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>H_f</td>
<td>Saturation Enthalpy</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>H_{tg}</td>
<td>Enthalpy change from saturated liquid to saturated vapor</td>
<td>Btu/lb</td>
</tr>
<tr>
<td>D_e</td>
<td>Hydraulic Equivalent Diameter</td>
<td>in.</td>
</tr>
<tr>
<td>G</td>
<td>Mass Velocity</td>
<td>lb/ft^2-hour</td>
</tr>
<tr>
<td>L</td>
<td>Length</td>
<td>in.</td>
</tr>
<tr>
<td>\rho_g</td>
<td>Vapor Density</td>
<td>lb/ft^3</td>
</tr>
<tr>
<td>\rho_L</td>
<td>Liquid Density</td>
<td>lb/ft^3</td>
</tr>
</tbody>
</table>


The correlation, given for an uniform and non uniform heat flux distribution, for round, rectangular channels and for clusters, has the following form:

\[
\frac{\hat{W}_{si}}{\gamma^i H_{ge}} = a_i \frac{L_s}{L_s + b}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\hat{W}_{si})</td>
<td>Total critical power input over (L_s) to surface (i) where the crisis sets on.</td>
<td>watt/cm²</td>
</tr>
<tr>
<td>(\gamma)</td>
<td>Mass Flowrate</td>
<td>g/sec</td>
</tr>
<tr>
<td>(H_{ge})</td>
<td>Enthalpy change upon vaporization</td>
<td>J/g</td>
</tr>
<tr>
<td>(a_i)</td>
<td>Constant dependent on the Pressure and mass velocity</td>
<td>(3)</td>
</tr>
<tr>
<td>(b)</td>
<td>Constant dependent on the Pressure, mass velocity and diameter</td>
<td>(4)</td>
</tr>
<tr>
<td>(L_s)</td>
<td>Saturation length</td>
<td>cm</td>
</tr>
<tr>
<td>(G)</td>
<td>Mass velocity</td>
<td>g/cm²·sec</td>
</tr>
<tr>
<td>(P)</td>
<td>Pressure</td>
<td>ata</td>
</tr>
</tbody>
</table>
(1) \[ \phi_{\text{max}} / \phi < 4 \]

(2) For complex geometries \( \phi \) must be multiplied by \( \frac{P_i}{P_{\text{tot}}} \)
where \( P_i \) is the perimeter of the surface \( i \), \( P_{\text{tot}} \) is the wetted perimeter.

(3) \[ a_i = \frac{1 - P / P_{\text{crit}}}{(G/100)^{1/3}} \quad \text{[C.G.S units]} \]

(4) \[ b = 0.315 \left( \frac{P_{\text{er}}}{P} - 1 \right)^{0.4} D^{1.4} G \quad \text{[C.G.S units]} \]
A Method of Representing Burnout Data in Two Phase Heat Transfer for Uniformly Heated Round Tubes

AERE - R 4613 November 1964

The correlation, given for an uniform heat flux distribution and for round tubes, may be written in the following form, obtained from graphs reported by author,

\[ x_0 = \frac{2.5 \alpha}{1 + \frac{G}{10^6}} \frac{L_s}{L_s + 8.18 \beta D^{4/5} \left( \frac{G}{10^6} \right)^{2/3}} \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_0 )</td>
<td>Burnout Steam Quality</td>
<td>Dimensionless number</td>
</tr>
<tr>
<td>( G )</td>
<td>Mass velocity</td>
<td>lb/ft²-hour</td>
</tr>
<tr>
<td>( D )</td>
<td>Diameter</td>
<td>in.</td>
</tr>
<tr>
<td>( L_s )</td>
<td>Saturation length</td>
<td>ft.</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>Constant dependent on the Pressure(1)</td>
<td></td>
</tr>
<tr>
<td>( \beta )</td>
<td>Constant dependent on the Pressure(1)</td>
<td></td>
</tr>
<tr>
<td>( P )</td>
<td>Pressure</td>
<td>ata</td>
</tr>
</tbody>
</table>

(1) \( \alpha = \alpha(P) \) and \( \beta = \beta(P) \) can be obtained by a simple expression which relate mathematically same experimental diagrams.
The correlation, given for an uniform and non uniform heat flux distribution, and for round ducts, has the following form (on the range in which \( q_{cr} \) decreases with \( W_q \) ) :

\[
q_{cr} = \frac{2.41 \times 10^9}{r} \frac{1}{A} \frac{\lambda}{\delta''} \left( \delta'' - \delta' \right) \left( \frac{Re_{mix}}{Re_0^{1.15}} \right)^{1.5} \frac{Pr}{Pr} \left( \frac{b}{d} \right) \left( \frac{\delta'}{\delta''} \right)^2
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_{cr} )</td>
<td>Burnout Heat Flux</td>
<td>kcal/m²-hour</td>
</tr>
<tr>
<td>( r )</td>
<td>Latent heat of vaporization</td>
<td>kcal/kg</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Thermal conductivity</td>
<td>kcal/m°C · hour</td>
</tr>
<tr>
<td>( A )</td>
<td>Heat Equivalent of mechanical work</td>
<td>kcal/kg</td>
</tr>
<tr>
<td>( T_{sat} )</td>
<td>Saturation Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>( \delta', \delta'' )</td>
<td>Liquid and Steam density</td>
<td>kg/m³</td>
</tr>
<tr>
<td>( Re_{mix} )</td>
<td>Reynold's number for the mixture</td>
<td>Adimensional</td>
</tr>
<tr>
<td>( Re_0 )</td>
<td>Reynold's number for the liquid</td>
<td>Adimensional</td>
</tr>
<tr>
<td>( Pr )</td>
<td>Prandtl's number</td>
<td>Adimensional</td>
</tr>
<tr>
<td>( \delta )</td>
<td>Surface Tension</td>
<td>kg/m</td>
</tr>
<tr>
<td>( d )</td>
<td>Diameter</td>
<td>m</td>
</tr>
</tbody>
</table>
The correlation, given for an uniform heat flux distribution and for round tubes, has the following complex form:

$$B = \frac{1}{V_{fg}} \left( \frac{m}{F} \right)^{1/2} \frac{q}{A}$$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Ratio between the droplet transfer coefficient and boiling velocity</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Kg</td>
<td>Droplet transfer coefficient</td>
<td>m/sec</td>
</tr>
<tr>
<td>Vb</td>
<td>Boiling Velocity</td>
<td>m/sec</td>
</tr>
<tr>
<td>Xbo</td>
<td>Burnout Steam Quality</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>E</td>
<td>Reentrainment coefficient</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>r</td>
<td>Ratio between the specific volume of the liquid and the specific volume change upon vaporization</td>
<td></td>
</tr>
<tr>
<td>Vf</td>
<td>Specific volume of the liquid</td>
<td>m$^3$/kg</td>
</tr>
<tr>
<td>Vfg</td>
<td>Specific volume change upon vaporization</td>
<td>m$^3$/kg</td>
</tr>
<tr>
<td>b</td>
<td>Droplet diffusion coefficient</td>
<td>kg$^{1/2}$/sec$^{2/3}$</td>
</tr>
<tr>
<td>hrfg</td>
<td>Latent heat of vaporization</td>
<td>kj/kg</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>( \dot{m}/F )</td>
<td>Mass velocity</td>
<td>( \text{kg/m}^2\ \text{sec} )</td>
</tr>
<tr>
<td>( q/A )</td>
<td>Burnout Heat Flux</td>
<td>( \text{kJ/m}^2\ \text{sec} )</td>
</tr>
</tbody>
</table>
An accurate and simple correlation for Burnout conditions in vertical Round Ducts AE - HTL - 798 June 1965

The correlation, given for an uniform heat flux distribution and for round ducts, has the following form:

\[ X_{bo} = a_0 \left( \frac{10^5}{G^{0.5} \frac{q}{A}} \right) - a_1 \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_{bo} )</td>
<td>Burnout Steam Quality</td>
<td>Adimensional</td>
</tr>
<tr>
<td>( G )</td>
<td>Mass Velocity</td>
<td>( \text{kg/m}^2 \text{-sec} )</td>
</tr>
<tr>
<td>( \frac{q}{A} )</td>
<td>Burnout Heat Flux</td>
<td>( \text{kJ/m}^2 \text{-sec} )</td>
</tr>
<tr>
<td>( a_0 )</td>
<td>Constant dependent on the Pressure (^{(1)})</td>
<td></td>
</tr>
<tr>
<td>( a_1 )</td>
<td>Constant dependent on the Pressure (^{(1)})</td>
<td></td>
</tr>
<tr>
<td>( P )</td>
<td>Pressure</td>
<td>( \text{kg/cm}^2 )</td>
</tr>
</tbody>
</table>

\(^{(1)}\) \( a_0 = a_0(P) \) and \( a_1 = a_1(P) \) can be obtained from the diagram in the fig. 2 of the above mentioned reference.
PART 2

STANDARD FORM
Standard Form

\[ \phi_e = 171 \frac{H_{lg} K}{D^{1/4}} \left( \frac{135.6}{G} \right)^n \left( \frac{1 - X_o}{X_o + \nu} \right) \text{ watt/cm}^2 \]

where \( n \) and \( k \) are constants dependent on the Pressure, given by means of the diagrams on the pages 641 and 649 of Energia Nucleare - Vol. 6 No. 10 - figures 1 and 15.

From such diagrams, we have obtained by means of a linear regression program, the following two approximated expressions for the pressure range 70-140 ata

\[ n = n(P) \approx -3.25 \cdot 10^{-4} P^2 + 5.57 \cdot 10^{-2} P - 0.835 \]

\[ k = k(P) \approx 1.73 \cdot 10^{-3} - 8.3 \cdot 10^{-6} P \]

Range of validity for the involved parameters

\[ G \quad 27 \leq G \leq 420 \quad \text{g/cm}^2 \text{ sec} \]

\[ P \quad 35 \leq P \leq 140 \quad \text{ata} \]

\[ D \quad 0.25 \leq D \leq 0.50 \quad \text{cm} \]

\[ L \quad \text{not given} \]
The range of validity for this correlation is the same as Bettis Plant correlation: namely it has been obtained by means of a "best-fit" on their experimental data.

Asymptotic Trend

\[ X_0 \rightarrow 0 \quad \phi_0 \rightarrow 171 \frac{H\log K}{D^{1/4}} \left( \frac{135.5}{G} \right)^n \frac{1}{\sqrt{\gamma}} \]

\[ X_0 \rightarrow 1 \quad \phi_0 \rightarrow 0 \]

\[ P \rightarrow P_{\text{crit}} \quad \phi_0 \rightarrow 0 \]

\[ G \rightarrow 0 \quad \phi_0 \rightarrow \infty \]

\[ G \rightarrow \infty \quad \phi_0 \rightarrow 0 \]
The correlation does not depend on $L$. 
There are two correlations, of which the first one is valid for $0/2 > \left[ \frac{4}{g(P_g - P)} \right]^{1/2}$, the second one for $0/2 < \left[ \frac{4}{g(P_g - P)} \right]^{1/2}$.

**1st Standard form**

$$\phi = \frac{G_{HLQ}}{4} \frac{4 f(P) (1 - X_o)^{-1.8 \cdot 10^{-6}} G X_o}{\mu_L \left[ g(P_g - P) / \frac{4}{g} \right]^{1/2} + 9 \cdot 10^{-5} G} \text{ watt/cm}^2$$

**2nd Standard form**

$$\phi = \frac{G_{HLQ}}{4} \frac{f(P) (1 - X_o)}{\mu_L \left[ g(P_g - P) / \frac{4}{g} \right]^{1/2} + 3.15 \cdot 10^{-4} G} \text{ watt/cm}^2$$

$$\phi = \frac{G_{HLQ} D}{4} \frac{4 f(P) (1 - X_o)^{-1.8 \cdot 10^{-6}} G X_o}{2/\mu_L + 9 \cdot 10^{-5} G D} \text{ watt/cm}^2$$
\[ 2) \quad \phi_o = \frac{H L \rho G \cdot D \cdot f(p) (1 - X_o)}{2 \mu L + 3,15 \cdot 10^{-4} G D} \quad \text{Watt/cm}^2 \]

The forms 1) and 1)\' must be used at low quality \[ \frac{H L G X_o}{4 \phi_o} \leq 12 \]

The forms 2) and 2)\' must be used at high quality \[ \frac{H L G X_o}{4 \phi_o} > 125 \]

\[ f(p) \text{ is a constant dependent on the pressure:} \]

\[ f(p) = 1,9 \cdot 10^{-5} \rho_g^{1/2} \left[ 69 \left( \rho_L - \rho_g \right) \right]^{1/4} \]

Range of validity for the involved parameters

- \( G \): \( 15 \leq G \leq 325 \) g/cm² sec
- \( P \): \( 1 \leq P \leq 220 \) ata
- \( D \): \( 0,02 \leq D \leq 3 \) cm
- \( L \): \( 3,5 \leq L \leq 180 \) cm
- \( L/D \): \( 1 \leq L/D \leq 220 \)
- \( X_o \): \( 0 < X_o < 1 \)
- \( X_{in} \): \( -0,8 < X_{in} < 0 \)
- \( \phi_o \): \( \phi_o \) not given

This range of validity is given by the author
Asymptotic Trend

\[
\begin{aligned}
X_0 \to 0 & \quad \left\{ \begin{array}{l}
\phi_o^{(1)} \to \frac{G H L g f(p)}{M_L \left[ g \left( \frac{P_L - P}{g} \right) / b \right]^{1/2} + 9 \cdot 10^{-5} G} \\
\phi_o^{(1)'} \to \frac{D g H L g f(p) - 10^{-5} G D}{2 M_L + 9 \cdot 10^{-5} G D}
\end{array} \right. \\
X_0 \to 1 & \quad \left\{ \begin{array}{l}
\phi_o^{(2)} \to 0 \\
\phi_o^{(2)'} \to 0
\end{array} \right. \\
\rho \to \rho_{\text{crit}} & \quad \left\{ \begin{array}{l}
\phi_o^{(1)(1)'} \to 0 \\
\phi_o^{(2)(2)'} \to 0
\end{array} \right. \\
G \to 0 & \quad \left\{ \begin{array}{l}
\phi_o^{(1)(1)'} \to 0 \\
\phi_o^{(2)(2)'} \to 0
\end{array} \right.
\end{aligned}
\]
The correlation does not depend on $L$.

Note—The standard form has been obtained taking $W = G/\rho_L$ and $K_3 = 50$. 

\[
\begin{align*}
G \to \infty & \quad \phi_o^{(1)(1)} \to -\infty \\
\phi_o^{(2)(2)} & \to \frac{H_{eq} f(p)(1-X_e)}{3.15 \times 10^4}
\end{align*}
\]
Standard form

\[ \phi_0 = c_1 H_{\text{Lg}}^{0.2} \left( \frac{G \rho}{\mu L} \right)^{0.6} \left( \frac{\mu}{\rho g} \right)^{0.08} \left( c_L (\Theta + 273) \right)^{0.8} (1 - \gamma) G^{0.4} \text{ watt/cm}^2 \]

where:

- \( c_1 \) is a constant dependent on the geometry and on the ratio \( L/D \).

Round and annular ducts

- \( 4.83 \times 10^{-5} \) when \( L/D > 100 \)
- \( 4.83 \times 10^{-5} \) when \( L/D < 100 \)

Rectangular Channels

- \( 6.22 \times 10^{-5} \) when \( L/D > 100 \)
- \( 6.22 \times 10^{-5} \) when \( L/D < 100 \)

\( c_1 \) is the smaller value between \( e^{0.0412 (100 - L/D)} \) and \( 0.373 \left[ \frac{G \mu L}{\rho g} (1 - \gamma) \right]^{0.4} \)

- \( n \) is a constant dependent on the geometry, on \( G \) and \( P \) :
Round and Annular ducts

\[
\begin{align*}
0.8 \text{ when } & \frac{G \mu_L}{\rho L} \left(\frac{p_L}{p_g}\right)^2 < 1.5 \times 10^{-2} \\
50 \text{ when } & \frac{G \mu_L}{\rho L} \left(\frac{p_L}{p_g}\right)^2 > 6 \times 10^{-2} \\
3 \text{ when } & \frac{G \mu_L}{\rho L} \left(\frac{p_L}{p_g}\right)^2 > 9 \times 10^{-2}
\end{align*}
\]

Rectangular Channels

\[
\begin{align*}
33.3 \text{ when } & \frac{G \mu_L}{\rho L} \left(\frac{p_L}{p_g}\right)^2 > 9 \times 10^{-2}
\end{align*}
\]

Range of validity for the involved parameters

\[
\begin{align*}
G^* & \quad \frac{20}{1000} \quad \text{g/cm}^2 \text{ sec} \\
P^* & \quad \frac{20}{200} \quad \text{ata} \\
D^* & \quad \begin{cases} 
D > 0.4 \quad \text{cm} \\
\frac{S}{L} < 0.13 \quad \text{cm}
\end{cases} \\
L & \quad \text{not given} \\
L/D & \quad \text{not given}
\end{align*}
\]
\[ x_0 \quad \rightarrow \quad 0 \quad \phi_0 \quad \rightarrow \quad \left( \frac{C}{D} \right)^{0.2} \left( \frac{H}{\mu_\varepsilon} \right)^{0.8} \left( \frac{\rho}{\mu_\varepsilon} \right)^{0.08} \left( \frac{c}{h} \right)^{0.8} \] 

\[ x_\text{in} \quad \rightarrow \quad \Delta T_{\text{sub}} < 150 \quad ^\circ \text{C} \]

These ranges of validity have been determined by us using the data which the correlation has been compared with.

\[ f > 0.13 \quad \text{cm} \quad \text{is referred to annular ducts.} \]

The authors have not given restrictions on \( L \) and \( L/D \) and \( \phi_0 \).

**Asymptotic Trend**

\[ x_0 \quad \rightarrow \quad 0 \quad \phi_0 \quad \rightarrow \quad 0 \]

\[ x_0 \quad \rightarrow \quad 1 \quad \phi_0 \quad \rightarrow \quad 0 \]

\[ P \quad \rightarrow \quad P_{\text{crit}} \quad \phi_0 \quad \rightarrow \quad 0 \]

\[ G \quad \rightarrow \quad 0 \quad \phi_0 \quad \rightarrow \quad 0 \]
when $D$ is fixed and $L$ increases, $\phi_0$ increases with $L$ and reaches the saturation for $L/D$ equal to 100.
S. Levy

Standard Form

\[ \Phi_0 = 0.7323 \ln \left( \frac{6 \rho_L^3 \gamma^2}{(1 + \gamma)^3} \right)^{1/4} + 0.18 \frac{K_h}{D} \left( \frac{G}{\mu_L} \right)^{0.8} \left( \frac{\mu_u C_L}{K_h} \right)^{0.33} \Phi_0^{1/4} \exp \left( - \frac{P}{63.3} \right) + \]

\[ - 0.595955 \ln \beta' \gamma \left( \frac{\rho_L}{6(1 + \gamma)} \right)^{1/4} \left( 10^5 \frac{\mu_u}{G} \right)^{1/6} D^{1/6} \text{ watt/cm}^2 \]

where \( \beta' \) is a constant dependent on the Pressure and on \( X_o \). We have calculated the following expressions for round and rectangular channels.

Round ducts

\[ P = 42 \text{ ata} \]
\[ X_o = 0.05 \quad \beta' = 0.10 \]
\[ 0.1 \leq X_o \leq 1 \quad \beta' = 0.11 + 0.46 X_o \]

\[ P = 71 \text{ ata} \]
\[ X_o = 0.05 \quad \beta' = 0.07 \]
\[ 0.1 \leq X_o \leq 1 \quad \beta' = 0.07 + 0.4 X_o \]

\[ P = 84 \text{ ata} \]
\[ X_o = 0.05 \quad \beta' = 0.06 \]
\[ 0.1 \leq X_o \leq 1 \quad \beta' = 0.06 + 0.37 X_o \]
\[ P = 142 \text{ ata} \begin{cases} 0 < X_\circ \leq 0.3 \\ 0.3 \leq X_\circ \leq 1 \end{cases} \quad \beta' = 0.533 X_\circ \]

\[ P = 71 \text{ ata} \begin{cases} X_\circ = 0.05 \\ 0.1 \leq X_\circ < 1 \end{cases} \quad \beta' = 0.065 \]

\[ P = 84 \text{ ata} \begin{cases} X_\circ = 0.05 \\ 0.1 \leq X_\circ < 1 \end{cases} \quad \beta' = 0.04 \]

\[ P = 142 \text{ ata} \begin{cases} X_\circ = 0.05 \\ 0.1 \leq X_\circ < 1 \end{cases} \quad \beta' = 0.03 \]

Range of validity for the involved parameters

\begin{align*}
G & \quad 20 \leq G \leq 380 \quad \text{g/cm}^2 \text{ sec} \\
P & \quad 42 \leq P \leq 140 \quad \text{ata} \\
D & \quad 0.13 \leq D \leq 0.46 \quad \text{cm} \\
L & \quad 30 \leq L \leq 81 \quad \text{cm}
\end{align*}
This range of validity is the "Probably Range of Validity".

Asymptotic Trend

\[
\begin{align*}
L/D & \geq 60 \\
X_0 & > 0 \\
X_{in} & < 0 \\
\phi_0 & \text{ not given}
\end{align*}
\]

The correlation does not depend on \( L \).
Standard Form

\[
\phi_e = \frac{H_{eg}}{X_0} D^{6\frac{5}{6}} \left[ \frac{\mu_e P_0}{\mu_0} \left( \frac{g (e - \rho)}{6} \right)^{1/2} \right] \left[ \frac{\mu_0}{\mu_e} \left( \frac{6}{g (e - \rho)} \right)^{1/2} \right]^{1/5} \left[ \frac{0.35 DG (1 - X_0) + 2492 \mu e P_0}{DG (1 - X_e) + 1400 \mu e P_0 / P_e} \right]^{1/5} \text{watt/cm}^2
\]

Range of validity for the involved parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>10</td>
<td>1320 g/cm² · sec</td>
</tr>
<tr>
<td>P</td>
<td>20</td>
<td>200 ata</td>
</tr>
<tr>
<td>D</td>
<td>0.4</td>
<td>3.22 cm.</td>
</tr>
<tr>
<td>L</td>
<td>150</td>
<td>300 cm.</td>
</tr>
<tr>
<td>L/D</td>
<td>93</td>
<td>375</td>
</tr>
<tr>
<td>X₀</td>
<td>&gt; 0.1</td>
<td></td>
</tr>
<tr>
<td>X_in</td>
<td>&lt; 0</td>
<td></td>
</tr>
<tr>
<td>( \phi_e )</td>
<td>10</td>
<td>390 watt/cm²</td>
</tr>
</tbody>
</table>

This range of validity is given by the authors.

(1) Assuming \( X_{av} = X_e \)

Asymptotic Trend

\( X_e \rightarrow 0 \quad \phi_e \rightarrow \infty \)
\[ \Phi_0 \rightarrow 0 \quad \text{as for } \chi_o \rightarrow 1 \]

\[ \frac{\chi_o}{\chi_o} \rightarrow 1 \quad \Phi_0 \rightarrow \frac{H_{eq} D^{0.5}}{P e} \left( \frac{\mu_e}{\rho_e} \left( \frac{P_e - P_g}{6} \right)^{1/2} \right) \left( \frac{\mu_g}{\rho_g} \left( \frac{P_e - P_g}{6} \right) \right)^{1/2} \left( \frac{2492}{1400} \right)^{8/5} \]

\[ P \rightarrow P_{\text{crit}} \]

\[ G \rightarrow 0 \quad \text{idem as for } \chi_o \rightarrow 1 \]

\[ G \rightarrow \infty \quad \Phi_0 \rightarrow \frac{H_{eq} D^{0.5}}{P e} \left( \frac{\mu_e}{\rho_e} \left( \frac{P_e - P_g}{6} \right)^{1/2} \right) \left( \frac{\mu_g}{\rho_g} \left( \frac{P_e - P_g}{6} \right) \right)^{1/2} \left( \frac{0.35}{1} \right)^{8/5} \]
Rybin

Standard Form

\[ \phi_e = H_{Lg} g \frac{1}{2} \left\{ g \, \delta \left( \rho_e - \rho_g \right) \right\}^{1/4} \left[ \frac{1 - (1 + \nu) n}{\gamma + X_0} \right] \text{ Watt/cm}^2 \]

where:

\( n \) and \( k_0 \) are two constants dependent on the Pressure and mass velocity.

\[ n = 0.08 \left\{ \frac{G}{\rho_L} \frac{4}{\sqrt{g}} \frac{\sqrt{\rho_L - \rho_g}}{6} \right\}^{0.55} \]

\[ k_0 = 0.0575 \left\{ \frac{G}{\rho_L} \frac{4}{\sqrt{g}} \frac{\sqrt{\rho_L - \rho_g}}{6} \right\}^{0.23} \text{ when } 14 < \frac{G}{\rho_L} \frac{4}{\sqrt{g}} \frac{\sqrt{\rho_L - \rho_g}}{6} \leq 50 \]

\[ k_0 = 0.01450 \left\{ \frac{G}{\rho_L} \frac{4}{\sqrt{g}} \frac{\sqrt{\rho_L - \rho_g}}{6} \right\}^{0.6} \text{ when } 50 < \frac{G}{\rho_L} \frac{4}{\sqrt{g}} \frac{\sqrt{\rho_L - \rho_g}}{6} \leq 80 \]
Range of validity for the involved parameters:

\( G \)  
\[ 80 \leq G \leq 700 \quad \text{g/cm}^2 \text{ sec} \]

\( p \)  
\[ 70 \leq p \leq 206 \quad \text{ata} \]

\( D \)  
\[ D > 0.6 \quad \text{cm} \]

\( L \)  
\[ L \quad \text{not given} \]

\( L/D \)  
\[ L/D \quad \text{not given} \]

\( X_0 \)  
\[ 0 < X_0 < \frac{0.85 \rho_g / \rho_l}{0.15 + 0.85 \rho_g / \rho_l} \]

\( X_{in} \)  
\[ X_{in} < 0 \]

\( \phi_0 \)  
\[ 65 \leq \phi_0 \leq 450 \quad \text{watt/cm}^2 \]

This range of validity is the "Probably Range of Validity".

Asymptotic Trend

\( X_0 \rightarrow 0 \)  
\[ \phi_0 \rightarrow H_k g \rho_g^{1/2} \left[ g \delta (\rho_L - \rho_g) \right]^{1/2} K_o \]

\( X_0 \rightarrow 1 \)  
\[ \phi_0 \rightarrow H_k g \rho_g^{1/2} \left[ g \delta (\rho_L - \rho_g) \right]^{1/2} K_o (1 - n) \]

\( P \rightarrow P_{cri} \)  
\[ \phi_0 \rightarrow 0 \]

55
For these values of $G$, $K_0$ is not defined and it is not possible to give the asymptotic Trend.

The correlation does not depend on $L$. 
Standard Form

It is necessary to distinguish two forms for this correlation.

The first form, given for a pressure of 70 ata only and containing the dependence on the ratio L/D, is

\[ \phi_0 = \frac{121.1 \times 10^6}{G^2} \left( \frac{L}{D} \right)^{-2/3} \left( \frac{1-X_o}{X_o + \gamma} \right)^2 \text{watt/cm}^2 \]

The second form, valid for all pressures \( \neq \) 70 ata, is

\[ \phi_0^m = K G^{-n} \left( \frac{1-X_o}{X_o + \gamma} \right) \text{watt/cm}^2 \]

where \( m, n \) and \( k \) are constants dependent on the pressure, given by means of the diagrams on the pages 185 (Fig. II 40), 186 (Fig. II 44) of CAN 1 Report [9].

Also in this case we have obtained, by means of a linear regression program, the following approximated expressions:

\[ m = m(P) \propto -10^{-5} P^2 + 5.83 \times 10^{-3} P + 0.12 \]
\[ n = n(P) \propto 1.3819 - 0.00459 P \]
\[ k = k(P) \propto 0.532 P^2 - 88 P + 6 \times 10^3 \]
Range of validity for the involved parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min. Value</th>
<th>Max. Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G )</td>
<td>100</td>
<td>450</td>
</tr>
<tr>
<td>( P )</td>
<td>45</td>
<td>85</td>
</tr>
<tr>
<td>( D )</td>
<td>0.3</td>
<td>1</td>
</tr>
<tr>
<td>( L )</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>( L/D )</td>
<td>20</td>
<td>266</td>
</tr>
</tbody>
</table>

\[ X_e \leq X_{\text{lim}} \]

\[ 0.05 \leq X_{\text{in}} \leq 0.7 \]

\[ 10 \leq \phi_e \leq 500 \]

This range of validity is given by the authors.

\((+)\) - \( X_{\text{lim}} \) is the value of \( X_e \) necessary in order to avoid the hydrodynamic perturbations effect.

Asymptotic Trend

\[ X_e \rightarrow 0 \]
\[ \phi_e \rightarrow \frac{1}{m} \]
\[ G_{\frac{n}{m}} \left( \frac{1}{Y} \right) \]

\[ X_e \rightarrow 1 \]
\[ \phi_e \rightarrow 0 \]

\[ P \rightarrow P_{\text{crit}} \]
\[ \phi_e \rightarrow \text{to value not defined because } m \text{ and } n \text{ are not defined.} \]

\[ G \rightarrow 0 \]
\[ \phi_e \rightarrow \infty \]

\[ G \rightarrow \infty \]
\[ \phi_e \rightarrow 0 \]

At 70 ata, \( \phi_e \) decreases with \( L/D \) increasing.
D. H. Lee - J. D. Obertelli

Standard Form

\[ \phi_0 = 360.5 \left( \frac{10^3 - 2326}{H g X_o + H_o} \right)^2 \left( 1 + \frac{73.98}{g} \right) \exp \left( -0.000165 \frac{L}{D} \right) \frac{\text{watt}}{\text{cm}^2} \]

Range of validity for the involved parameters

- \( G \): \( 102 \leq G \leq 225 \) \( \text{g/cm}^2 \text{ sec} \)
- \( P \): \( P = 70 \) \( \text{ata} \)
- \( D \): \( 0.56 \leq D \leq 1.15 \) \( \text{cm} \)
- \( L \): \( 22 \leq L \leq 135 \) \( \text{cm} \)
- \( L/D \): \( 39 \leq L/D \leq 360 \)
- \( X_o \): \( X_o > 0 \)
- \( X_{in} \): \( -0.23 < X_{in} < 0 \)
- \( \phi_0 \): \( \phi_0 \) \( \text{not given} \)

This range of validity is given by the authors.
Asymptotic Trend

\[ x_o \rightarrow 0 \quad \phi_o \rightarrow \frac{1.95 \cdot 10^9}{H_s^2} \left(1 + \frac{73.98}{G}\right) \exp\left(-\frac{0.0165 L/D}{1.955 + D}\right) \]

\[ x_o \rightarrow 1 \quad \phi_o \rightarrow 1.95 \frac{10^9}{(H_{lg} + H_s)^2} \left(1 + \frac{73.98}{G}\right) \exp\left(-\frac{0.0165 L/D}{1.955 + D}\right) \]

\[ P \rightarrow P_{crit} \quad \phi_o \rightarrow \infty \]

\[ G \rightarrow \infty \quad \phi_o \rightarrow 1.95 \frac{10^9}{(H_{lg} X_o H_s)^2} \exp\left(-\frac{0.0165 L/D}{1.955 + D}\right) \]

\[ \phi_o \text{ decreases with } L/D. \]
Correlation for low velocity and Mound ducts

Standard form

\[ \phi_0 = H^E \left( \frac{G}{1.356} \right)^{1/2} (1 - X_o) \text{ watt/cm}^2 \]

Range of validity for the involved parameters

\[
\begin{align*}
G & \quad 1.36 \leq G \leq 84 \quad \text{g/cm}^2 \text{ sec} \\
P & \quad 1.06 \leq P \leq 141 \quad \text{ata} \\
D & \quad 0.304 \leq D \leq 0.99 \quad \text{cm} \\
L & \quad 15.2 \leq L \leq 310 \quad \text{cm} \\
L/D & \quad L/D > 50 \\
X_o & \quad 0 < X_o < 1 \\
X_{in} & \quad -1.31 < X_{in} \leq 0 \\
\phi_0 & \quad \phi_0 \quad \text{not given}
\end{align*}
\]

This range of validity is the "Probably Range of Validity".
Asymptotic Trend

\[ X_0 \rightarrow 0 \quad \phi_0 \rightarrow \frac{H_2 g \left( \frac{G}{135,6} \right)^{1/2}}{\Phi / \Phi} \]

\[ X \rightarrow 1 \quad \phi_0 \rightarrow 0 \]

\[ P \rightarrow P_{\text{crit}} \quad \phi_0 \rightarrow 0 \]

\[ G \rightarrow 0 \quad \phi_0 \rightarrow 0 \]

The correlation does not depend on L.
R. V. Macbeth

Correlation for low velocity and rectangular ducts

Standard Form

\[ \phi_0 = 11.66 H_{\text{el}} \frac{\gamma^{1/3}}{G^{0.1}} \left( 1 - X_0 \right) \text{ watt/cm}^2 \]

Range of validity for the involved parameters

- \( G \): 2.21 \( \leq \) \( G \) \( \leq \) 75 g/cm\(^2\) sec
- \( P \): 56 \( \leq \) \( P \) \( \leq \) 141 ata
- \( \delta \): 0.13 \( \leq \) \( \delta \) \( \leq \) 0.256 cm.
- \( L \): 15.2 \( \leq \) \( L \) \( \leq \) 64.8 cm.
- \( L/D \): 60 \( \leq \) \( L/D \) \( \leq \) 460
- \( X_0 \): 0 \( \leq \) \( X_0 \) \( \leq \) 1
- \( X_{\text{in}} \): \(-1.35 \leq X_{\text{in}} < 0\)
- \( \phi_0 \), \( \phi_e \) not given

This range of validity is the "Probably Range of Validity".

- \( X_0 \mapsto 0 \)
- \( \phi_0 \mapsto 11.66 H_{\text{el}} \frac{\gamma^{1/3}}{G^{0.1}} \)
- \( \phi_0 \mapsto 0 \)
- \( \phi_0 \mapsto \infty \)
- \( \phi_0 \mapsto 0 \)

The correlation does not depend on \( L \).
Correlation for High velocity and Round ducts

Standard Form

\[ \Phi_o = G \left[ 2.325 \gamma_4 \left( \frac{D}{2.54} \right)^{Y_2-1} \left( \frac{G}{1356} \right)^{Y_2-1} - 0.25 \gamma_3 H_2 \left( \frac{D}{2.54} \right)^{-0.4} \left( \frac{G}{1356} \right)^{Y_4} \right] \text{ Wall/cm}^2 \]

where the \( \gamma \) are constants dependent on the Pressure, given

Range of validity for the involved parameters

- \( G \): \( 1.356 \leq G \leq 1060 \) g/cm\(^2\) sec
- \( P \): \( 1.06 \leq P \leq 193 \) ata
- \( D \): \( 0.101 \leq D \leq 2.37 \) cm.
- \( L \): \( 2.54 \leq L \leq 310 \) cm.
- \( L/D \): \( L/D \geq 8.5 \)
- \( X \): \( 0 < X < 1 \)
- \( X_{in} \): \( -2.5 < X_{in} < 0 \)
- \( \Phi \): \( \Phi \) not given.

This range of validity is the "Probably Range of Validity".

Asymptotic Trend

\[ X_o \to 0 \quad \Phi_o \to G \left[ 2.325 \gamma_4 \left( \frac{D}{2.54} \right)^{Y_2-1} \left( \frac{G}{1356} \right)^{Y_2-1} \right] \]
For $P \rightarrow P_{\text{crit}}$, the asymptotic trend is not defined because the constants $y_1$ are given for some particular pressures only.

\[ G \rightarrow \infty \quad \phi_0 \rightarrow \pm \infty \] in correspondence of the values of $y_2$ and $y_4$.

The correlation does not depend on $L$.

Table I for the values of the constants $y_i$.

<table>
<thead>
<tr>
<th>$P_{\text{ata}}$</th>
<th>$y_1$</th>
<th>$y_2$</th>
<th>$y_3$</th>
<th>$y_4$</th>
<th>$y_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.05</td>
<td>-0.211</td>
<td>-0.324</td>
<td>+ 0.0010</td>
<td>-1.05</td>
<td>+1.12</td>
</tr>
<tr>
<td>17.5</td>
<td>-0.533</td>
<td>-0.266</td>
<td>+ 0.0166</td>
<td>-0.937</td>
<td>+1.77</td>
</tr>
<tr>
<td>37</td>
<td>-0.566</td>
<td>-0.329</td>
<td>+ 0.0127</td>
<td>-0.737</td>
<td>+1.57</td>
</tr>
<tr>
<td>70</td>
<td>-0.487</td>
<td>-0.179</td>
<td>+ 0.0085</td>
<td>-0.555</td>
<td>+1.06</td>
</tr>
<tr>
<td>110</td>
<td>-0.527</td>
<td>+0.024</td>
<td>+ 0.0121</td>
<td>-0.096</td>
<td>+0.720</td>
</tr>
<tr>
<td>140</td>
<td>-0.268</td>
<td>0.192</td>
<td>+ 0.0093</td>
<td>-0.343</td>
<td>+0.627</td>
</tr>
<tr>
<td>190</td>
<td>-1.45</td>
<td>+0.489</td>
<td>+ 0.0097</td>
<td>-0.529</td>
<td>+0.0124</td>
</tr>
</tbody>
</table>
Correlation for high velocity and rectangular ducts

Standard Form

$$\Phi_0 = G \left\{ 2,325 y_0 \left( \frac{\delta}{2,54} \right) \left( \frac{G}{1356} \right)^{y_2^{-1}} - 0,555 H \left( \frac{\delta}{2,54} \right) ^{-0,4} \right\} \frac{G}{1356} \left( \frac{X_o}{X_0} \right) \text{ watt/cm}^2$$

where the $y_i$ are constants dependent on the Pressure, given by means of table II.

Range of validity for the involved parameters

- $G$ \(13.56 \leq G \leq 648\) g/cm$^2$ sec
- $P$ \(42 \leq P \leq 141\) ata
- $0.13 \leq \delta \leq 0.256$ cm.
- $L$ \(15.2 \leq L \leq 68.4\) cm.
- $L/\delta$ \(60 \leq L/\delta \leq 460\)
- $X_o$ \(0 < X_o < 1\)
- $X_{in}$ \(-0.8 \leq X_{in} < 0\)

This range of validity is the "Probably Range of Validity".

Asymptotic Trend

$$X_o \rightarrow 0 \quad \Phi_0 \rightarrow G \left\{ 2,325 y_0 \left( \frac{\delta}{2,54} \right) \left( \frac{G}{1356} \right)^{y_2^{-1}} \right\}$$

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\[
I. \quad \begin{align*}
\phi_b &= G \left\{ 2.325 \gamma_i \left( \frac{d}{2.54} \right)^{\gamma_i} \left( \frac{G}{1356} \right)^{-1} - 0.555 \right\} \\
& \quad \left( \frac{d}{2.54} \right)^{-0.4} \left( \frac{G}{1356} \right)^{\gamma_i}
\end{align*}
\]

For \( P \to P_{\text{crit}} \), the asymptotic trend is not defined because the constants \( \gamma_i \) are given for some particular pressures only.

For \( G \to \infty \), \( \phi_0 \to \pm \infty \) in correspondence with the values of \( \gamma_i \), whose values oscillate from negative values to positive ones.

The correlation does not depend on \( \theta \).

**Table II** for the values of the constants \( \gamma_i \)

<table>
<thead>
<tr>
<th>( P )</th>
<th>( \gamma_0 )</th>
<th>( \gamma_1 )</th>
<th>( \gamma_2 )</th>
<th>( \gamma_3 )</th>
<th>( \gamma_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.6</td>
<td>+23.4</td>
<td>-0.472</td>
<td>-3.29</td>
<td>+0.123</td>
<td>-3.93</td>
</tr>
<tr>
<td>43.5</td>
<td>+0.445</td>
<td>-1.01</td>
<td>+0.384</td>
<td>+0.0096</td>
<td>-0.0067</td>
</tr>
<tr>
<td>88</td>
<td>+1.88</td>
<td>-0.081</td>
<td>-0.526</td>
<td>+0.0035</td>
<td>-1.29</td>
</tr>
<tr>
<td>146</td>
<td>+0.546</td>
<td>-0.315</td>
<td>-0.056</td>
<td>+0.0027</td>
<td>-0.725</td>
</tr>
</tbody>
</table>
Standard Form

\[ \phi_e = 1.11 \times 10^{-2} \frac{H_{eg}^{1.58}}{L} \left( 1 - 5.07 \times 10^{-2} \left( \frac{\rho}{\rho_e} \right)^{0.731} G \left( X_e - X_e \right) \right) \text{ watt/cm}^2 \]

where \( X_e \) is a constant which is equal to 0 for unilateral internal heating and equal to \( \frac{\Phi_{NB}}{G H_{eg} S_f} \) for bilateral internal heating.

\( \Phi_{NB} \) is the heat flux through the wall which is not in burnout.

\( S_{RNB} \) is the heated surface of the wall which is not in burnout.

\( S_f \) is the flux cross-section.

Range of validity for the involved parameters

- \( G \) \( 36 \leq G \leq 310 \) g/cm² sec
- \( P \) \( 100 \leq P \leq 185 \) ata
- \( D \) \( 0.6 \leq D \leq 1.2 \) cm.
  \( 0.1 \leq \delta \leq 0.2 \) cm.
- \( L \) \( 10 \leq L \leq 40 \) cm.
- \( L/D \) \( L/D \) not given
- \( X_e \) \( X_e < 0.2 \)
- \( X_{in} \) \( X_{in} < 0 \)
- \( \phi_0 \) \( \phi_0 \) not given
This range of validity is given by the authors.

**Asymptotic Trend**

\[
X \to 0 \quad \phi_0 \to 1.11 \cdot 10^{-2} \cdot \frac{H_g^{1.58}}{L^{0.262}} \left[1 + 5.07 \cdot 10^{-2} \left(\frac{g}{g_c}\right)^{0.731} G \cdot X_c\right]
\]

\[
X \to 0 \quad \phi_0 \to 1.11 \cdot 10^{-2} \cdot \frac{H_g^{1.58}}{L^{0.262}}
\]

\[
G \to 0 \quad \phi_0 \to +\infty \quad \text{when } X_c \geq X_0
\]

\[
\phi_0 \text{ decreases monotonically with } L.
\]
Standard Form

\[ \Phi = \frac{4.18 \times 10^3}{D^{0.48}} \left( \frac{G \cdot 3.6 \times 10^4}{P} \right)^n \left( \frac{\rho_f}{\rho_g} \right)^{2.2} \left[ 1 + \frac{8 \cdot 10^9}{(3.6 \times 10^4 G)^K} \right] \left( 1 - X_0 \right) m \text{ watt/cm}^2 \]

where:

- \( m \) and \( n \) are two constants dependent on the Pressure, \( k \) is a constant dependent on the Pressure and the outlet quality.

\[ m = m(P) = 0.7 \frac{\rho_f}{\rho_g} - 0.4 \]

\[ n = n(P) = 0.56 - 0.0189 \frac{\rho_f}{\rho_g} \]

\[ K = K(P, X_0) = 1.13 + 3.6 \frac{\rho_g}{\rho_f} - 0.45 X_0 \]

Range of validity for the involved parameters:

- \( G \): \( 110 \leq G \leq 500 \) g/cm² sec
- \( P \): \( 100 \leq P \leq 200 \) ata
- \( D \): \( 0.4 \leq D \leq 1.2 \) cm
- \( L \): \( L \geq 20 \) cm
- \( L/D \): \( L/D \) not given
This Range of validity is given by the authors.

Asymptotic Trend

\[ X_o \rightarrow 0 \quad \phi_0 \rightarrow \frac{4.18 \cdot 10^3}{D^{0.48}} \left( G \cdot 3.6 \cdot 10^4 \right)^n \left( \frac{P_c}{P_g} \right)^{2.2} \left\{ 1 + \frac{8 \cdot 10^9}{(3.6 \cdot 10^4 G)^K} \right\} \]

\[ X_o \rightarrow 1 \quad \phi_0 \rightarrow 0 \]

\[ P \rightarrow P_{crit} \quad \phi_0 \rightarrow \frac{4.18 \cdot 10^3}{D^{0.48}} \left( G \cdot 3.6 \cdot 10^4 \right)^n \left( 1 + \frac{8 \cdot 10^9}{(3.6 \cdot 10^4 G)^K} \right) \left( 1 - X_o \right)^m \]

\[ m \rightarrow 0.3 \quad n \rightarrow 0.5411 \]

\[ K \rightarrow 4.73 - 0.45 X_o \]

\[ G \rightarrow 0 \quad \phi_0 \rightarrow \infty \]

\[ G \rightarrow \infty \quad \phi_0 \rightarrow 0 \]

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2nd correlation (Average Pressure)

Standard Form

\[ \phi_0 = \frac{0.376}{D^{0.48}} \left[ 5.1 \times 10^{-3} H_{L,2}^{1.72} (1-X_o)^m - G \right] \text{ watt/cm}^2 \]

where \( m \) is a constant dependent on the pressure.

\[ m = m(P) = 3.48 - 12.9 \times 10^{-4} H_L \]

Range of validity for the involved parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G )</td>
<td>56</td>
<td>500</td>
</tr>
<tr>
<td>( P )</td>
<td>40</td>
<td>100</td>
</tr>
<tr>
<td>( D )</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>( L/D )</td>
<td>not given</td>
<td>not given</td>
</tr>
<tr>
<td>( X_o )</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>( X_{in} )</td>
<td>not given</td>
<td>not given</td>
</tr>
<tr>
<td>( \phi_0 )</td>
<td>not given</td>
<td>not given</td>
</tr>
</tbody>
</table>

This range of validity is given by the authors.

Asymptotic Trend

\[ X_o \to 0 \quad \phi_0 = \frac{0.376}{D^{0.48}} \left( 5.1 H_{L,2}^{1.72} \times 10^{-3} - G \right) \]
\[ \chi. \rho \quad \varphi \quad \gamma \quad \delta \quad \varepsilon \quad \zeta \quad \eta \quad \theta \quad \iota \quad \kappa \quad \lambda \quad \mu \quad \nu \quad \xi \quad \omicron \quad \pi \quad \rho \quad \sigma \quad \tau \quad \upsilon \quad \phi \quad \chi \quad \psi \quad \omega \]

\[ \rho \rightarrow \text{to values} \leq 0 \]

\[ P \quad \rightarrow \quad P_{\text{crit}} \quad \varphi \rightarrow -\frac{0.376 \, G}{D^{0.44}} \]

\[ G \rightarrow 0 \quad \varphi \rightarrow \frac{0.376}{D^{0.44}} [5.110^{-3} \, H_1^{1.12} (1 - X_o)^m] \]

\[ g \rightarrow \infty \quad \varphi \rightarrow -\infty \]

The correlation does not depend on \( L \).
Standard Form

\[ \phi_0 = 315.4 \frac{A' - 3.12 \times 10^{-4} D G H_e X_e}{C'} \]

\[ A' = Y_0 \left( \frac{D}{2.54} \right)^{Y_1} \left( \frac{G}{135.6} \right)^{Y_2} \left( 1 + Y_3 \frac{D}{2.54} + Y_4 \frac{G}{135.6} + \frac{Y_5}{344} \right) \]

\[ C' = Y_6 \left( \frac{D}{2.54} \right)^{Y_7} \left( \frac{G}{135.6} \right)^{Y_8} \left( 1 + Y_9 \frac{D}{2.54} + \frac{Y_{10}}{135.6} + \frac{Y_{11}}{344} \right) \]

where the \( y_i \) constants dependent on the pressure, are given in the enclosed table III.

Range of validity for the involved parameters

\[ 1 \leq G \leq 1800 \text{ g/cm}^2 \text{ sec} \]

\( P \) defined only for \( P=40,70,110,140 \text{ ata} \)

\[ 0.09 \leq D \leq 2.5 \text{ cm} \]

\[ 2.54 \leq L \leq 366 \text{ cm} \]
This range of validity is the "Probably Range of Validity ".

Asymptotic Trend

\[ X_\infty \rightarrow 0 \quad \phi_0 \rightarrow \frac{315.4}{C'} \]

\[ X_\infty \rightarrow 1 \quad \phi_0 \rightarrow 315.4 \frac{A'}{C'} - 3.12 \times 10^4 G D H_f, \]

\[ P \rightarrow p_{cr} \text{ not defined} \]

\[ G \rightarrow 0 \quad \phi_0 \rightarrow 0 \text{ for } 140 \text{ ata} \]
\[ \phi_0 \rightarrow \infty \text{ for } 40, 70, 110 \text{ ata} \]

\[ G \rightarrow \infty \quad \phi_0 \rightarrow 0 \text{ for } 40, 70, 110 \text{ ata} \]
\[ \phi_0 \rightarrow \infty \text{ for } 140 \text{ ata} \]
Table III

OPTIMAL VALUES FOR $Y_1$

<table>
<thead>
<tr>
<th>System Pressure atm</th>
<th>40</th>
<th>70</th>
<th>110</th>
<th>140</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_0$</td>
<td>237</td>
<td>114</td>
<td>36,0</td>
<td>65,5</td>
</tr>
<tr>
<td>$Y_1$</td>
<td>1,20</td>
<td>0,811</td>
<td>0,509</td>
<td>1,19</td>
</tr>
<tr>
<td>$Y_2$</td>
<td>0,425</td>
<td>0,221</td>
<td>-0,109</td>
<td>0,376</td>
</tr>
<tr>
<td>$Y_3$</td>
<td>-0,940</td>
<td>-0,128</td>
<td>-0,190</td>
<td>-0,577</td>
</tr>
<tr>
<td>$Y_4$</td>
<td>-0,0324</td>
<td>0,0274</td>
<td>0,0240</td>
<td>0,220</td>
</tr>
<tr>
<td>$Y_5$</td>
<td>0,111</td>
<td>-0,0667</td>
<td>0,463</td>
<td>-0,373</td>
</tr>
<tr>
<td>$Y_6$</td>
<td>19,3</td>
<td>127</td>
<td>41,7</td>
<td>17,1</td>
</tr>
<tr>
<td>$Y_7$</td>
<td>0,959</td>
<td>1,32</td>
<td>0,953</td>
<td>1,18</td>
</tr>
<tr>
<td>$Y_8$</td>
<td>0,831</td>
<td>0,411</td>
<td>0,0109</td>
<td>-0,456</td>
</tr>
<tr>
<td>$Y_9$</td>
<td>2,61</td>
<td>-0,274</td>
<td>0,231</td>
<td>-1,53</td>
</tr>
<tr>
<td>$Y_{10}$</td>
<td>-0,0578</td>
<td>-0,0397</td>
<td>0,0767</td>
<td>2,75</td>
</tr>
<tr>
<td>$Y_{11}$</td>
<td>0,124</td>
<td>-0,0221</td>
<td>0,117</td>
<td>2,24</td>
</tr>
</tbody>
</table>
Standard Form

\[ \phi = 3.63 \cdot c_2 \left( \frac{H_{03} \left(1 + \frac{D}{\mu_e} \right)}{G^{0.45} D^{0.07} \mu_e^{0.05} \left(1 + \sqrt{\frac{D}{\mu_e}} \right)^{3/2}} \cdot \left( \frac{D}{\mu_e} + \frac{1 + X_0 (C_l - 1)}{1 - X_0} \right) \right)^{-1/4} \text{ W/}\text{cm}^2 \]

where \( c_1 \) and \( c_2 \) are two constants dependent on the geometry.

- \( c_1 \) is equal to 6.5 for one surface heated annular channels and equal to 1 for round ducts and both surfaces heated rectangular channels.
- \( c_2 \) for round ducts, is equal to 0.53 when \( D > 0.426 \) and to 0.53 \( \left( \frac{D}{0.426} \right) \) when \( D < 0.426 \).
- \( c_2 \) for rectangular ducts, and annular channels is equal to 0.86 when \( D > 0.855 \) and to 0.86 \( \left( \frac{D}{0.855} \right)^{0.9} \) when \( D < 0.855 \).

**Range of validity for the involved parameters**

- **G**: \( 24 \leq G \leq 440 \) \text{ g/cm}^2\text{-sec}
- **P**: \( 42 \leq P \leq 175 \) \text{ ata}
- **D**: \( 0.122 \leq D \leq 1.22 \) \text{ cm} \text{ Round ducts}
$D \quad 0.244 \leq D \leq 2.44 \text{ cm}$

$L/D \quad 20 \leq L/D \leq 400$

$L^{(t)} \quad 15 \leq L \geq 275 \text{ cm}$

$x_* \quad 0 \leq x_* \geq 0.75$

$x_{in} \quad x_{in} \text{ not given}$

$\phi_0 \quad \phi_0 \text{ not given}$

- "Probably Range of Validity".

Asymptotic Trend

$X_0 \rightarrow 0 \quad \phi_0 \rightarrow 3.63 \left( 2 \frac{H \left( \frac{1 + R_1/R_2}{D} \right) P_2}{G^{0.45}D^{0.6} \mu \sqrt{\frac{1 + R_1/R_2}{D}}} \right)^{5/14} 5/14 \times 1/2$

$X_0 \rightarrow 1 \quad \phi_0 \rightarrow 0$

$P \rightarrow P_{crit} \quad \phi_0 \rightarrow 0$

$G \rightarrow 0 \quad \phi_0 \rightarrow \infty$

$G \rightarrow \infty \quad \phi_0 \rightarrow 0$
Standard Form

\[ \phi_0 = \frac{9}{32} \sqrt{\frac{H_t g G D}{L}} \left\{ \frac{17}{9} \left[ \left(0.825 + 2.36 e^{-0.67D}\right) e^{-0.0116} - 0.41 e^{-0.0048LID} \right] - 1.12 \frac{p}{\rho_e} + 0.548 \right\} - X_0 \]

Range of validity for the involved parameters

\[ G \quad 54 \leq G \leq 550 \text{ g/cm}^2 \text{ sec} \]
\[ P \quad 55 \leq P \leq 150 \text{ ata} \]
\[ D \quad 0.254 \leq D \leq 1.37 \text{ cm} \]
\[ L \quad 23 \leq L \leq 195 \text{ cm} \]
\[ L/D \quad 21 \leq L/D \leq 660 \]
\[ X_0 \quad 0 < X_0 < 0.9 \]
\[ X_{in} \quad 0 > X_{in} > \frac{930 - H_s}{H_t g} \]
\[ \phi_0 \quad 30 < \phi_0 < 550 \text{ watt/cm}^2 \]
\[ P_{Re}/P \quad 0.88 \leq \frac{P_{Re}}{P} \leq 1 \]
Asymptotic Trend

\[ x_0 \rightarrow 0 \quad \phi_0 \rightarrow \frac{17}{32} \frac{G D}{L} \ln \left( \frac{0.825 + 2.36 e^{-0.911 G}}{e - 0.41 e - 1.12 \int_{0}^{L} \frac{g}{g} + 0.548} \right) \]

\[ x_0 \rightarrow 1 \quad \phi_0 \rightarrow \frac{9}{32} \frac{G D}{L} \ln \left( \frac{0.825 + 2.36 e^{-0.911 G}}{e - 0.41 e - 1.12 \int_{0}^{L} \frac{g}{g} + 0.548} \right) \]

\[ P \rightarrow P_{\text{crit}} \quad \phi_0 \rightarrow 0 \]

\[ G \rightarrow 0 \quad \phi_0 \rightarrow 0 \]

\[ G \rightarrow \infty \quad \phi_0 \rightarrow \infty \]

when \( L \) increases, \( \phi_0 \rightarrow 0 \).
Standard Form

\[
\phi_0 = \frac{0.794}{D^{4/3}} \left( \frac{P_{cr} - P}{P_{cr} G / 100} \right)^{1/4} \left(a - X_0 \right)
\]

where \( a = \frac{P_{cr} - P}{P_{cr} G / 100} \)

Range of validity for the involved parameters

- \( G \): 
  \( 100 \left( 1 - \frac{P}{P_{cr}} \right)^3 \leq G \leq 400 \) g/cm² sec
- \( P \): 
  \( 45 \leq P \leq 150 \) ata
- \( D \): 
  \( D > 0.7 \) cm.
- \( L^{(+)} \): 
  \( 20.3 \leq L \leq 267 \) cm.
- \( L/D \): 
  \( L/D \) not given
- \( X_0 \): 
  \( X_0 > 0 \)
- \( X_{in} \): 
  \( X_{in} \leq 0.2 \)
- \( \phi_0 \): 
  \( \phi_0 \) not given

This range of validity is given by the authors.

\((+)\) determined by an examination of the \( L \) used during the experiments.

Asymptotic Trend

\[
X_0 \rightarrow 0 \quad \phi_0 \rightarrow \frac{0.794 H_{ls} P^{a/4}}{D^{4/3} \left( P_{cr} - P \right)^{a/4}}
\]
$X_o \rightarrow 1 \quad \phi_o \rightarrow$ to negative values

when $P \rightarrow P_{\text{crit}}$ the correlation is given only for the point $\phi_o = 0$

$X_o = 0$

$G \rightarrow 0$

$G \rightarrow \infty$ the correlation is reduced to a straight line $X_e = \theta$.

The correlation does not depend on $L$. 
G. F. Hewitt

Standard Form

\[ \phi_0 = 0.115 \frac{-1.356}{G^{1.3} \text{Heg}} \left\{ \frac{2.5 \lambda(P)}{1 + \frac{6}{135.6}} - X_0 \right\} \text{watt/cm}^2 \]

This correlation is an analytical approximation of the graphical correlation of Hewitt. \( \lambda(P) \) and \( \beta(P) \) are two constants depending on the Pressure, having the following approximated expressions:

\[ \lambda = \lambda(P) \equiv -0.3126 \times 10^8 P^4 + 0.133 \times 10^2 P + 0.7123 \]

\[ \beta = \beta(P) \text{ is given as ratio with } \lambda(P) \]

\[ \lambda(P)/\beta(P) \equiv 0.34 + 9.4/(P - 7.3) \]

Range of validity for the involved parameters:

- \( G \): \( 58 \leq G \leq 410 \) g/cm² sec
- \( P \): \( 49 \leq P \leq 112 \) ata
- \( D \): \( 0.55 \leq D \leq 1.13 \) cm.
- \( L \): \( 21 \leq L \leq 205 \) cm.
- \( L/D \): \( 39 \leq L/D \leq 360 \)
- \( X_0 \): \( X_0 > 0 \)
- \( X_{\text{in}} \): \(-0.37 < X_{\text{in}} < 0 \)
- \( \phi_0 \): \( \phi_0 \) not given

Asymptotic Trend

\[ X_0 \to 0 \quad \phi_0 \to 0.115 \frac{-1.356}{G^{1.3} \text{Heg}} \left\{ \frac{2.5 \lambda(P)}{1 + \frac{6}{135.6}} - X_0 \right\} \]
\[
\begin{align*}
\chi_0 &\rightarrow 1 \\
\phi_0 &\rightarrow 0.115 \left( \frac{3/5}{0} \right)^{1/3} \frac{g^{1/3}}{\beta(p)} \frac{H_{eq}}{1 + \frac{G}{1356}} \left( \frac{2.5}{\lambda(p)} \right)^{-1}
\end{align*}
\]

\( P \rightarrow \chi_{\text{crit}} \) for this value \( \lambda(p) \) and \( \beta(p) \) are not defined.

\( 0 \rightarrow \infty \) \( \phi_0 \) is reduced to the point \( \phi_0 = 0; \chi_0 = 0 \)

\( 0 \rightarrow 0 \) \( \phi_0 \rightarrow 0 \)

The correlation does not depend on \( L \).
Standard Form

$$\phi_0 = 2.36 \cdot 10^5 \frac{(\Theta + 273) K}{H_g} \left( \frac{S_L - P_g}{S_g} \right)^{0.75} \frac{L^2}{g} \left( \frac{G}{g} \right)^{0.25} \left( \frac{\mu_L}{\mu_g} \right)^{0.45} \left( \frac{P_f^2}{D^{0.95}} \right) \left( 1 + \frac{\mu_L}{\mu_g} - 1 \right) x_o \right)^3 \text{ watt/cm}^2$$

We have considered only the trend in which $\phi_0$ is a decreasing function of mass velocity.

Range of validity for the involved parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Unit</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G$</td>
<td>$100 \leq G \leq 800$</td>
<td>g/cm$^2$ sec</td>
<td></td>
</tr>
<tr>
<td>$P$</td>
<td>$98 \lesssim P \lesssim 196$</td>
<td>ata</td>
<td>when $X_0 &gt; 0.05$</td>
</tr>
<tr>
<td>$P$</td>
<td>$78 \lesssim P &lt; 98$</td>
<td>ata</td>
<td>when $X_0 &gt; 0.10$</td>
</tr>
<tr>
<td>$P$</td>
<td>$49 \lesssim P &lt; 78$</td>
<td>ata</td>
<td>when $X_0 &gt; 0.15$</td>
</tr>
<tr>
<td>$D$</td>
<td>$0.5 \leq D \leq 1.6$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L$</td>
<td>$L &gt; 260$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L/D$</td>
<td>$L/D$ not given</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$$X_0 > \frac{2.11 \cdot 10^5 G D^{0.45} \left( \frac{D}{S_L - S_g} \right)^{0.25}}{(\frac{P}{P_{crit}})^{-2.28} \left( \frac{\mu_L}{\mu_g} - 1 \right) + (\frac{P}{P_{crit}}) - 1}$$

$$X_{in} < 0$$

$\phi_0$ not given

(+) - This restriction is not given explicitly.
The range of validity is given by the authors.

Asymptotic Trend

\[ x_0 \rightarrow 0 \quad \phi_0 \rightarrow 2.36 \cdot 10^{5} \left( \frac{\Theta + 2.73}{H_e g} \right)^{3/2} \left( \frac{\rho_c}{\rho} \right)^{0.75} \left( \frac{\sigma}{g} \right)^{0.25} \left( \frac{\mu_e}{\mu} \right)^{0.45} \frac{P_r^2}{D^{0.95}} \]

\[ x_0 \rightarrow 1 \quad \phi_0 \rightarrow 2.36 \cdot 10^{5} \left( \frac{\Theta + 2.73}{H_e g} \right)^{3/2} \left( \frac{\rho_c}{\rho} \right)^{0.75} \left( \frac{\sigma}{g} \right)^{0.25} \left( \frac{\mu_e}{\mu} \right)^{0.45} \frac{P_r^2}{D^{0.95}} \left( \frac{\mu_c}{\mu} \right) \frac{S_c}{S} \]

\[ P \rightarrow P_{cr} \quad \phi_0 \rightarrow 0 \]

\[ G \rightarrow 0 \quad \phi_0 \rightarrow \infty \]

\[ G \rightarrow \infty \quad \phi_0 \rightarrow 0 \]

The correlation does not depend on \( L \).
We determine first of all
\[ \phi_0 = \frac{b}{V_L g \frac{H_L g}{B}} \text{ Watt/cm}^2 \]

where
\[ B = \frac{-\log(1 - x_0^b) + \log\left(0.98 - \frac{\varepsilon v B^{1/2}}{x_0^{1/4}(B+1)}\right) - \log\left(1 - \frac{\varepsilon (x_0^b + v)}{1-x_0^b} B^{1/2}\right)}{\log \frac{x_0^b + v}{v}} \]

Successively we find \( \phi_0 \) and \( X_0 \) by means of the two expressions:

\[ \phi_0 = K_d \phi_p \text{ Watt/cm}^2 \]
\[ X_0 = \frac{4(K_d - 1)}{G H_L g D} \phi_p \]

\( \varepsilon \) and \( b \) are two constants dependent on the Pressure, \( k_d \) is a constant dependent on the diameter. These constants are given by means of the diagram of the Report AE-178.

By means of a linear regression program we have determined the following approximated expressions:

\[ \varepsilon = \varepsilon(p) \approx -0.385 \cdot 10^6 p^3 + 2.1867 \cdot 10^4 p^2 - 2.1182 \cdot 10^2 p + 0.5913 \]
\[ b = b(p) = \frac{1.0677}{p} - 0.668 \cdot 10^6 p^3 + 0.199 \cdot 10^{-3} p^2 - 0.02184 p + 1.0876 \]

\[ 0.9 + 0.29 e^{-4.25(D-0.5)^2} \]

\[ K_d = K_d(D) = \begin{cases} 1.019 - 0.048 D & D < 1.2 \\ 1.019 - 0.048 D & D \geq 1.2 \end{cases} \]

Range of validity for the involved parameters:

- \( G \): \( 12 \leq G \leq 545 \) g/cm\(^2\) sec
- \( P \): \( 2.7 \leq P \leq 101 \) ata
- \( D \): \( 0.4 \leq D \leq 2.5 \) cm.
- \( L \): \( 40 \leq L \leq 390 \) cm.
- \( L/D \): \( 40 \leq L/D \leq 890 \)
- \( X_0 \): \( 0 \leq X_0 < 1 \)

\( X_{in} \) corresponding to \( 30 < \Delta T < 240 \) °C

\( \phi_0 \): \( 35 < \phi_0 < 686 \) watt/cm\(^2\)

This range of validity is given by the authors.
Asymptotic Trend

\[ X_0 \rightarrow 0.02 \quad \phi_0 \text{ has an asymptote} \]
\[ X_0 \rightarrow 1 \quad \phi_0 \rightarrow 0 \]
\[ P \rightarrow P_{\text{crit}} \quad \text{for this value } \phi_0 \text{ is not defined} \]
\[ G \rightarrow 0 \quad \phi_0 \rightarrow \infty \]
\[ G \rightarrow \infty \quad \phi_0 \rightarrow 0 \]

The correlation does not depend on \( L \).
Standard Form

We determine first of all

\[ \phi_0^* = \frac{3.16 \cdot 10^3}{G^{1/2} \left( a_4 + \frac{X_0}{a_0} \right)} \text{ Watt/cm}^2 \]

where \( a_0 \) and \( a_4 \) are two constants dependent on the Pressure which may be determined by means of the diagrams of the Report RTL-798 (fig. 2). By means of a linear regression Program we have determined the following approximated expressions:

\[ a_0 = a_0(P) \approx -118.505/P^2 + 0.113281 \cdot 10^5 P^3 - 0.196885 \cdot 10^{-3} P^2 + 1.13773 \]
\[ a_1 = a_1(P) \approx 0.196257 \cdot 10^{-6} P^3 - 0.124829 \cdot 10^{-2} P + 0.40475 \]

Successively we find \( \phi_0 \) and \( X_0 \) by means of:

\[ \phi_0 = K_d \phi_0^* \text{ Watt/cm}^2 \]

\[ X_0 = X_0^* + \frac{4 \left( K_d - 1 \right) L}{G \cdot \text{Heg} \cdot D} \phi_0^* \]
**k**<sub>d</sub> is a constant dependent on the diameter, given by the diagram of the Report ETL-798 (fig. 3). By means of a linear regression program we have obtained from such a diagram the following approximated expression:

\[
K_d = K_d(D) = \begin{cases} 
0.9 + 0.29 e^{-4.25(D-0.5)^2} & D < 1.2 \\
1.019 - 0.048 D & D \geq 1.2
\end{cases}
\]

Range of validity for the involved parameters:

- \( G \) \( 12 \leq G \leq 700 \text{ g/cm}^2 \text{ sec} \)
- \( P \) \( 20 \leq P \leq 91 \text{ ata} \)
- \( D \) \( 0.4 \leq D \leq 3.75 \text{ cm} \)
- \( L \) \( 40 \leq L \leq 375 \text{ cm} \)
- \( L/D \) \( 40 \leq L/D \leq 890 \)
- \( X_o \) \(-0.05 < X_o \leq 0.5 \)

\( \chi \) corresponding to \( 30 < \Delta T_{\text{sub}} < 240 \text{ °C} \)

- \( \phi_o \) \( 50 \leq \phi_o \leq 700 \text{ watt/cm}^2 \).

This range of validity is given by the author.
Asymptotic Trend

\[ \chi \to 0 \quad \phi_0 \to \frac{3.6 \cdot 10^3}{a_4 G^{1/2}} \]

\[ \chi \to 1 \quad \phi_0 \to \frac{3.6 \cdot 10^3}{G^{1/2} \left( a_1 + \frac{1}{a_0} \right)} \]

For \( P \to P_{crit} \), \( a_0 \) and \( a_4 \) are not defined.

\[ G \to 0 \quad \phi \to \infty \]

\[ G \to W \quad \phi \to 0 \]

The correlation does not depend on \( L \).
RANGE OF VALIDITY FOR G

Given by the authors

Probably Range of Validity

Fig. 1
93
RANGE OF VALIDITY FOR PRESSURE

Average Pressure

High Pressure

Low G

High G

Low G

High G

RYBIN
MIROPOLSKII
ZENKEVITCH
KONKOV
IVASHKEVITCH
SMOLIN
MACBETH Rectangular
MACBETH Bound
TONG
LEVY
TIPPETS
LEE
BECKER 2nd
BECKER 1st
HEWITT
CLISE 3rd
CLISE 2nd
CLISE 1st

- given by the authors
- Probably Range of Validity

Fig. 2

94
RANGE OF VALIDITY FOR D

- RYBIN
- MAROPOLESIL
- ZENKOVIITCH
- KONKOV
- AVASHKOVIITCH
- SMOLIN
- MACBETH Rectangular
- MACBETH Round
- TONG
- LÉVY
- TAPPETS
- LECK
- BECKER 2nd
- BECKER 1st
- HAWITT
- CISE 3rd
- CISE 2nd
- CISE 1st

- RANGE OF VALIDITY

---

Fig. 3

given by the authors

Probably Range of Validity
RANGE OF VALIDITY FOR L

Fig. 4

given by the authors

it is not given a limit on the right

Probably Range of Validity
RANGE OF VALIDITY FOR L/D

Fig. 5

97
RANGE OF VALIDITY FOR $x_c$

given by the authors
depending on pressure

Probably Range of Validity

Fig. 6
98
<table>
<thead>
<tr>
<th></th>
<th>G</th>
<th>P</th>
<th>D</th>
<th>L</th>
<th>L/D</th>
<th>X₀</th>
<th>Xᵢₙ</th>
<th>φ₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>CISE I</td>
<td>27-420</td>
<td>35-140</td>
<td>0.25-0.5</td>
<td>-</td>
<td>21-365</td>
<td>0.15-0.80</td>
<td>&lt;0</td>
<td>63-630</td>
</tr>
<tr>
<td>CISE II</td>
<td>100-450</td>
<td>45-85</td>
<td>0.3-1</td>
<td>10-80</td>
<td>20-266</td>
<td>&lt; Xᵢₙ≤₀ &lt;0.05-0.7</td>
<td>10-500</td>
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<tr>
<td>CISE III</td>
<td>G(P)</td>
<td>45-150</td>
<td>&gt;0.7</td>
<td>20.3-267</td>
<td>-</td>
<td>&gt;0</td>
<td>&lt;0.2</td>
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<td>Hewitt</td>
<td>58-410</td>
<td>49-112</td>
<td>0.55-1.13</td>
<td>21-205</td>
<td>39-360</td>
<td>&gt;0</td>
<td>&lt;0.37-0</td>
<td>-</td>
</tr>
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<td>Becker I</td>
<td>12-545</td>
<td>2.7-101</td>
<td>0.4-2.5</td>
<td>40-390</td>
<td>40-890</td>
<td>0-1</td>
<td>-</td>
<td>35-686</td>
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<tr>
<td>Becker II</td>
<td>12-700</td>
<td>20-91</td>
<td>0.4-3.75</td>
<td>40-375</td>
<td>40-890</td>
<td>&gt;0.05-0.5</td>
<td>-</td>
<td>50-700</td>
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<td>Lee-Ober</td>
<td>102-225</td>
<td>70</td>
<td>0.56-1.15</td>
<td>22-135</td>
<td>39-360</td>
<td>&gt;0</td>
<td>&lt;0.23-0</td>
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<tr>
<td>Tippets</td>
<td>24-440</td>
<td>42-175</td>
<td>0.122-1.22</td>
<td>15-275</td>
<td>20-400</td>
<td>0-0.75</td>
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<td>-</td>
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<tr>
<td></td>
<td>G</td>
<td>P</td>
<td>D</td>
<td>L</td>
<td>L/D</td>
<td>(X_o)</td>
<td>(X_{in})</td>
<td>(\Phi)</td>
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<tr>
<td>Levy</td>
<td>20-380</td>
<td>42-140</td>
<td>0.13-0.46</td>
<td>30-81</td>
<td>&gt;60</td>
<td>&gt;0</td>
<td>&lt;0</td>
<td>-</td>
</tr>
<tr>
<td>Tong</td>
<td>54-550</td>
<td>55-150</td>
<td>0.254-1.37</td>
<td>23-195</td>
<td>21-660</td>
<td>0-0.9</td>
<td>-</td>
<td>30-550</td>
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<tr>
<td>Macbeth Re. Low G</td>
<td>1.36-84</td>
<td>1.06-141</td>
<td>0.304-0.99</td>
<td>15.2-310</td>
<td>&gt;50</td>
<td>0-1</td>
<td>-1.31-0</td>
<td>-</td>
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<tr>
<td>Macbeth Re. Low G</td>
<td>2.21-75</td>
<td>56-141</td>
<td>0.13-0.256</td>
<td>15.2-64.8</td>
<td>60-460</td>
<td>0-1</td>
<td>-1.25-0</td>
<td>-</td>
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<tr>
<td>Macbeth II</td>
<td>1-1800</td>
<td>49-196</td>
<td>0.09-2.5</td>
<td>2.54-366</td>
<td>-</td>
<td>0-1</td>
<td>&lt;0</td>
<td>-</td>
</tr>
<tr>
<td>Smolin</td>
<td>100-800</td>
<td>49-196</td>
<td>0.5-1.6</td>
<td>&gt;260</td>
<td>-</td>
<td>(X_o(P))</td>
<td>&lt;0</td>
<td>-</td>
</tr>
<tr>
<td>Ivashkevitch</td>
<td>15-325</td>
<td>1-220</td>
<td>0.02-3</td>
<td>3.5-180</td>
<td>1-220</td>
<td>0-1.0</td>
<td>-0.8-0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>P</td>
<td>D</td>
<td>L</td>
<td>L/D</td>
<td>X_0</td>
<td>X_{in}</td>
<td>\phi_0</td>
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<tr>
<td>Macbeth</td>
<td>1.356-1060</td>
<td>1.06-193</td>
<td>0.101-2.37</td>
<td>2.54-310</td>
<td>&gt; 50</td>
<td>0-1</td>
<td>-2.5-0</td>
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<tr>
<td>High G</td>
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<td>Macbeth</td>
<td>13.56-648</td>
<td>42-141</td>
<td>0.13-0.256</td>
<td>15.2-68.4</td>
<td>60-660</td>
<td>0-1</td>
<td>-1.435-0</td>
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<tr>
<td>Konkov</td>
<td>10-1320</td>
<td>20-200</td>
<td>0.4-3.22</td>
<td>150-300</td>
<td>93-375</td>
<td>&gt; 0.1</td>
<td>&lt; 0</td>
<td>10-390</td>
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<tr>
<td>Zenkevitch</td>
<td>56-110-500</td>
<td>40-100-200</td>
<td>0.4-1.2</td>
<td>20</td>
<td>-</td>
<td>0-0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Miropolskii</td>
<td>20-1000</td>
<td>20-200</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>&lt; 0.8</td>
<td>dep. on P</td>
<td>-</td>
</tr>
<tr>
<td>Ribin</td>
<td>80-700</td>
<td>70-206</td>
<td>&gt; 0.6</td>
<td>-</td>
<td>-</td>
<td>&gt; 0</td>
<td>&lt; 0</td>
<td>65-450</td>
</tr>
</tbody>
</table>
PART 3

GRAPHICAL COMPARISON
\[
\Phi_0 \text{ watr/cm}^2 \\
\begin{align*}
&0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1 \\
&0 \quad 100 \quad 200 \quad 300 \quad 400 \quad 500 \\
\end{align*}
\]

- **CISE 3\textsuperscript{rd}**
- **TONG**
- **HEWITT**
- **MACBETH 1\textsuperscript{st}, 2\textsuperscript{nd}**
- **IVASHKEVITCH**

**Fig. 7**

\[P = 7.2 \text{ atm} \]
\[D = 0.918 \text{ cm} \]
\[L = 139.9 \text{ cm} \]
\[G = 219 \text{ gr/cm}^2 \text{ sec} \]
\( \Phi \) watt/cm\(^2\)

- BECKER 1st, 2nd
- ZENKEVITCH
- LEVY
- MIROPOLSKI
- TIPPETS

Fig. 8

\begin{align*}
P &= 72 \text{ ata} \\
G &= 219 \text{ gr/cm}^2\text{ sec} \\
D &= 0.918 \text{ cm} \\
L &= 139.9 \text{ cm}
\end{align*}
Fig. 9

P = 72 ata  
G = 219 gr/cm² sec

D = 0.918 cm  
L = 139.9 cm

οοοο LEE

----- SMOLIN

----- RYBIN

----- CISE 1ˢᵗ

----- CISE 2ⁿᵈ

++++ KON KOV

φ₀ watt/cm²

0 0.2 0.4 0.6 0.8 1

X₀
\( \phi_0 \text{ watt/cm}^2 \)

- **CISE 3\(^{rd}\)**
- **TONG**
- **HEWITT**
- **MACBETH 1\(^{st}\)**
- **MACBETH 2\(^{nd}\)**
- **IVASHKEVITCH**

Fig. 10

\( X_{in} = 0 \)  
\( G = 219 \text{ gr/cm}^2 \text{ sec} \)  
\( D = 0.918 \text{ cm} \)  
\( L = 139.9 \text{ cm} \)
Fig. 11

\[ X = 0 \, \quad G = 219 \, \text{gr/cm}^2 \text{ sec} \]

\[ D = 0.918 \, \quad L = 139.9 \]
Fig. 12

$X_h = 0$

$G = 218 \text{ g/cm}^2 \text{ sec}$

$L = 139.9 \text{ cm}$

$\theta = 0.918 \text{ cm}$

$L = 139.9 \text{ cm}$

$\phi \text{ watt/cm}^2$

Para

Lee

Rybin

Konkov

Cise1st

Cise2nd

Smolin
Fig. 13

\[ \Phi_0 \text{ watt/cm}^2 \]

- CISE 3\textsuperscript{rd}
- TONG
- HEWITT
- MACBETH \textsuperscript{1st}, \textsuperscript{2nd}
- IVASHKEVITCH

\[ P = 72 \text{ ata} \]
\[ X_{in} = 0 \]
\[ D = 0.918 \text{ cm} \]
\[ L = 139.9 \text{ cm} \]
Fig. 14

P = 72 ata
X₀ = 0
D = 0.918 cm
L = 139.9 cm

BECKER 1st
ZENKEVITCH
LEVY
MIROPOLSKII
TIPPETS

Φ₀ watt/cm²

G gr/cm² sec
$\Phi_o\text{ watt/cm}^2$

---

$P = 72\text{ ata}$
$D = 0.918\text{ cm}$
$L = 139.9\text{ cm}$

Fig. 15

---

$X_{\infty} = 0$
$\phi_0$ watt/cm$^2$

- CISE 3$^{rd}$
- TONG
- HEWITT
- MACBETH 2$^{nd}$
- IVASHKEVITCH

$P = 72$ ata, $X_m = 0$
$D = 0.918$ cm, $G = 219$ gr/cm$^2$ sec

Fig 16

112
Fig. 17

$P = 72$ ata
$D = 0.918$ cm
$X_{in} = 0$
$G = 219$ gr/cm$^2$ sec
Fig. 18

\[ \Phi_0 \text{ watt/cm}^2 \]

- ○○○○ LEE
- --- SMOLIN
- --- CISE 1\text{st}
- + CISE 2\text{nd}
- • RYBIN
- + + + KONKOV

\[ P = 72 \text{ atm} \]
\[ X_{im} = 0 \]
\[ D = 0.918 \text{ cm} \]
\[ 6 = 219 \text{ gr/cm}^2 \text{ sec} \]
Fig. 19

P=72 ata  \hspace{1em} X_{in}=0

G=219 gr/cm\(^3\)sec  \hspace{1em} L=139.9 cm
Fig. 20

\[ \phi_{\text{watt/cm}^2} \]

- LEVY
- BECKER 1\textsuperscript{st}, 2\textsuperscript{nd}
- TIPPETS
- ZENKEVITCH
- MIROPOLSKII

P = 72 \text{ ata}
X_{in} = 0
L = 139.9 \text{ cm}
G = 219 \text{ gr/cm}^2 \text{ sec}

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For our graphical comparisons we have used the following correlations for the steam water physical properties (ref.26):

\[ \Theta = 118.052 \cdot P^{0.22151} - 17.778 \]

\[ H_s = 408.86 \cdot P^{0.26452} \quad \text{for} \quad 7 < P < 70 \]

\[ H_s = 337.73 \cdot P^{0.30934} \quad \text{for} \quad 70 < P < 140 \]

\[ H_{s3} = 214.4, 89.87 - 13.4 \cdot P + 8.07524 \cdot 10^{-2} \cdot P^2 - 2.82159 \cdot 10^{-4} \cdot P^3 \]

\[ \nu_s = \frac{1.87903 \cdot 10^{-3}}{P} - 7.866 \quad \text{for} \quad 7 < P < 24 \]

\[ \nu_s = \frac{2.3 \cdot 10^{-3}}{P} - 6.242 \quad 21 < P < 140 \]

\[ \rho_s = 1.022078 - 4.9862 \cdot 10^{-4} \cdot \Theta + 3.3705 \cdot 10^{-7} \cdot \Theta^2 - 6.33927 \cdot 10^{-9} \cdot \Theta^3 \]

\[ \sigma = 70.043 \left( \rho_s - \rho_4 \right)^4 \]

\[ \mu_s = \frac{10^{-2}}{3.7 \cdot 10^{0.2} \cdot \Theta - 0.22282} \]

\[ \mu_s = 0.56478 \cdot 10^{-4} + 0.524722 \cdot 10^{-6} \cdot \Theta + \frac{4.21847 \cdot 10^{-4}}{\Theta - 374.5} \]

\[ C_s = -8.32376 + 0.18411 \cdot \Theta - 0.8582 \cdot 10^{-3} \cdot \Theta^2 + 1.371 \cdot 10^{-6} \cdot \Theta^3 \]

\[ R = 0.41688 \cdot 10^{-15} \cdot \Theta^5 - 0.35633 \cdot 10^{-12} \cdot \Theta^4 + 0.180574 \cdot 10^{-5} \cdot \Theta + 6.705 \cdot 10^{-3} \]
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<td>equivalent diameter $\frac{4S}{P}$</td>
<td>cm., L</td>
</tr>
<tr>
<td>D_{he}</td>
<td>equivalent heated diameter $\frac{4S}{P_{he}}$</td>
<td>cm, L</td>
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<td>G</td>
<td>mass velocity $\frac{g}{2} cm \ sec$</td>
<td>M L^{-2} T^{-1}</td>
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<td>L^2 T^{-2}</td>
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<td>L² T^{-2}</td>
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<tr>
<td>--------</td>
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<td>g</td>
<td>acceleration due to gravity</td>
<td>( \frac{\text{cm}}{\text{sec}^2} ) LT(^{-2})</td>
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<td>thermal conductivity</td>
<td>( \frac{\text{watt}}{\text{cm} \cdot \text{K}} ) MLT(^{-3})</td>
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<td>P(_{he})</td>
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<td>vapor specific volume</td>
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<td>( \frac{v_L}{v_{3g}} )</td>
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<tr>
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<td>vapor density</td>
<td>( \frac{g}{\text{cm}^3} ) ML(^{-3})</td>
</tr>
<tr>
<td>ρ(_L)</td>
<td>liquid density</td>
<td>( \frac{g}{\text{cm}^3} ) ML(^{-3})</td>
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<td>σ</td>
<td>surface tension</td>
<td>dine/cm M T(^{-2})</td>
</tr>
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<td>( \frac{\text{watt}}{\text{cm}^2} ) M T(^{-3})</td>
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<td>gap</td>
<td>cm L</td>
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Alfred Nobel
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