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EUROPEAN ATOMIC ENERGY COMMUNITY — EURATOM

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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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 :

$$\varnothing_0 = \varnothing_0 (X_0)$$

where $\varnothing_0$ is the burnout heat flux, X_o 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_o, X_{in}, $\varnothing_0$) 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 : $17.5 \leqslant P \leqslant 140$ ata
$50 \leqslant G \leqslant 700$ g/cm² sec $\quad 0.2 \leqslant D \leqslant 2.5$ cm $\quad 20 \leqslant L \leqslant 250$ cm.

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Summary

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ACKNOWLEGMENT

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.

LIST OF CORRELATIONS

Introduction (*)

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 :

$$\phi_o = \phi_o(X_o)$$

where ϕ_o is the burnout heat flux, X_o the burnout steam quality at the outlet. Symbols and units have been standardyzed and are reported in the Table I.

For each correlation the range of validity of the most important parameters ($G, P, D, L, L/D, X_o, X_{in}, \phi_o$) 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 $\lim \phi_o(X_o \to 0)$, $\lim \phi_o(X_o \to 1)$, $\lim \phi_o(P \to P_{crit})$, $\lim \phi_o(G \to 0)$, $\lim \phi_o(G \to$ 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 ata, G=219 gr/cm^{2}sec, D=0,918 cm, and L=139,9 cm. In the figures 7-9, we have reported the critical heat flux versus th outlet quality, for X_{in}=0 and three parameters of the set P,G, D,L are fixed, plots of ϕ_o versus the free parameter are given in Figures (10-21), with ϕ_o vs. P in Figures (11-15), ϕ_o vs. L in Figures (16-18), and ϕ_o vs. D in figures (19-21). The parameters were examined for the following ranges :

$17{,}5 \leq P \leq 140$ ata $\quad 50 \leq G \leq 700$ gr/cm^{2}sec $\quad 0{,}2 \leq D \leq 2{,}5$ cm $\quad 20 \leq L \leq 250$ cm.

For each correlation the trend of ϕ_o 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

A. Cicchetti - M. Silvestri et al .

Energia Nucleare - Vol. 6 , No. 10 , pages 637-660 October 1959

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

$$W_B G^n = \frac{K' \lambda}{D^{0,25}} \quad \frac{100 - X}{X + a}$$

Symbol	Definition	Units
W_B	Burnout Heat Flux	10^6 Btu/ft^2 - hour
G	Mass velocity	10^6 lb/ft^2 - hour
D	Hydraulic Equivalent Diameter	in.
λ	Latent Heat of vaporization	Btu/lb
X	Burnout Steam Quality	dimensionless
a	Ratio between specific volume of liquid and specific volume change upon vaporization	dimensionless
V_f	Specific volume of liquid	ft^3/lb
V_{gf}	Specific volume change upon vaporization	ft^3/lb
K'	Pressure dependent constant (1)	
n	Pressure dependent constant (1)	
P	Pressure	p.s.i.a.

(1) 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.

A. A. Ivashkevitch

Critical Heat Flows in the Forced flow of liquid in channels

*Atomnaya Energiya - Vol. 8 , No. 1 , pages 51-53 January 1960

**Teploenergetika Vol. 8 , No. 10 pages 74-78 October 1961

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

$$K_{cr} = \frac{1{,}9 \cdot 10^{-5} \cdot Re}{1 + 1{,}8 \cdot 10^{-6} \frac{Re}{\varphi} \left(K_3 + K_4\right)}$$

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

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

$$Re = \begin{cases} \dfrac{W}{\nu'} \left(\dfrac{\sigma}{\gamma' - \gamma''} \right)^{1/2} & \text{when} \quad D \geq \left(\dfrac{\sigma}{\gamma' - \gamma''} \right)^{1} \\[2ex] \dfrac{W\,D}{\nu'} & \text{when} \quad D \leq \left(\dfrac{\sigma}{\gamma' - \gamma''} \right)^{1} \end{cases}$$

$$K_3 = \begin{cases} l_1 \left(\dfrac{\gamma' - \gamma''}{\sigma} \right) = K_3^* & \text{when } K_3^* \leqslant 50 \\ 50 & \text{when } K_3^* \geqslant 50 \end{cases}$$

$$K_4 = \begin{cases} \dfrac{l_2}{d_H} = K_4^* & \text{when } K_4^* \leqslant 125 \\ 125 & \text{when } K_4^* \geqslant 125 \end{cases}$$

Symbol	Definition	Units
q_{cr}	Burnout Heat Flux	kcal/m^2-hour
r	Latent heat of vaporization	kcal/kg
X	Burnout Steam Quality	dimensionless
g	Gravity acceleration	m/h^2
γ', γ''	Liquid and Steam specific gravity	kg/m^3
σ	Surface Tension	kg/m
ν'	Kinematic viscosity of the liquid	m^2/h
l_1	Distance between the section at wich subcooled surface boiling begins and the section under consideration can be obtained by a further correlation	m

W	liquid (*) or flow (**) velocity	m/h
l_2	Distance between the section at which saturated net boiling begins and the section under consideration.	m
δ	Gap for rectangular and annular channels	m
d_H	Hydraulic equivalent diameter	m
D	$\begin{cases} d_H/2 & \text{for round ducts} \\ \delta/2 & \text{for rectangular and annular channels with bilateral heating} \\ \delta & \text{for rectangular and annular channels with unilateral heating} \end{cases}$	m

(1) For an uniform heat flux distribution $\varphi = 1$

For non uniform heat flux distribution

$\varphi = q/\bar{q}$ with $\bar{q} = \frac{1}{P}\int^{P} q\, dP$ for radial nonuniformity

P is the perimeter

$$\bar{q} = \frac{1}{b}\int^{b} q\, db$$ for axial nonuniformity

b is the distance between the inlet section and the section in consideration

when $\frac{b}{d_H} > 125$, the integration is made between $b-125\ d_H$ and b

Z. H. Miropol'skii - M. E. Shitsman

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 lenght 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 :

$$\frac{q_{cr}\,\mu'}{\sigma\,\gamma' r} = c_1 \left(\frac{c_p' T_s}{r}\right)^{0.8} K_w^{0.4} \left(1 - X\right)^n$$

Symbol	Definition	Units
q_{cr}	Burnout Heat Flux	kcal/m^2-hour
μ'	Liquid absolute viscosity	kg-sec /m^2
σ	Surface Tension	kg/m
γ'	Liquid Density at T_{sat}	kg/m^3
r	Latent heat of vaporization	kcal/kg
c_1	Constant dependent on the Geometry (1)	
T_s	Saturation Temperature	°K
K_w	Constant dependent on the pressure, mass velocity (2)	dimensionless
X	Burnout Steam Quality	dimensionless
n	Constant dependent on K_w (3)	"
W_g	Massvelocity	kg/m^2-sec
c_p	Liquid specific heat	kcal/kg-°C

(1) c_1 is a constant dependent on the geometry and on the ratio L/D

(2) $$K_W = \frac{W_g\,\mu'}{\sigma\,\gamma'}\left(\frac{\gamma'}{\gamma''}\right)^{0.2}$$

(3) For round ducts and annular channels : $n = 0.8$ if $k_w < 1.6\,10^{-2}$; $n = 50\,k_w$ if $1.6\,10^{-2} \leq k_w \leq 6.10^{-2}$; $n = 3$ if $k_w > 6\,10^{-2}$

For rectangular channels : $n = 33.3\,k_w$ if $2.10^{-2} \leq k_w \leq 9.10^{-2}$; $n = 3$ if $k_w > 9.10^{-2}$

c_1
- Round and annular ducts
  - 0.174 when $L/D > 100$
  - $0.174\,c_1^*$ when $L/D < 100$
- Rectangular channels
  - 0.224 when $L/D > 100$
  - $0.224\,c_1^*$ when $L/D < 100$

and where c_1^* is the smaller value between $e^{+0.0122(100 - L/D)}$ and

$$0{,}373\left[\frac{W_g\,\mu'}{\sigma\,\gamma'}\left(\frac{\gamma'}{\gamma''}\right)^{0{,}2}\left(1-x\right)^{2{,}5\,n}\right]^{-0{,}4}$$

S. Levy

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:

$$\left(\frac{q}{A}\right)_p + \left(\frac{q}{A}\right)_F + \left(\frac{q}{A}\right)_M = 0{,}131\, h_{fg} \rho_v \left[\frac{\sigma g^2 (\rho_L - \rho_v)}{\rho_v^2} \right]^{1/4} + h_L \left(T_w - T_s\right) + h_L \, \Delta T_{sub} - h_{fg} \cdot M_v$$

with $M_v = \frac{C \rho_L}{\mu_L} \frac{K^2 \beta^2}{1 - \rho_v/\rho_L} G$

Symbol	Definition	Units
$(q/A)_p$	Burnout Heat Flux for the pool boiling	Btu/hour
$(q/A)_F$	Burnout Heat Flux for the Forced convection	Btu/hour
$(q/A)_M$	Burnout Heat Flux for the Mass Transfer	Btu/hour
h_{fg}	Latent heat of vaporization	Btu/lb
ρ_v	Vapor Density	lb/ft^3
σ	Surface Tension	lb/ft
g	Gravitational Constant	$ft/hour^2$
ρ_L	Liquid Density	lb/ft^3
h_L	Heat transfer coefficient for the liquid	Btu/hour-ft^2-°F
T_w	Wall Temperature	°F
T_s	Saturation Temperature	°F

ΔT_{sub}	Subcooling	^{o}F
C	Diffusion coefficient	ft^2/hour
μ_e	Liquid absolute viscosity	lb/hour-ft
K	Mixing length constant	Dimensionless
β	Dimensionless constant (1) dependent on the Pressure and Quality	
G	Mass velocity	lb/hour-ft^2

(1) β can be obtained by the tables on pages 6 and 7 in the above mentioned references

A. S. Kon'kov - V. V. Modnikova

Experimental investigation of the condition of deterioration of heat transfer during boiling in tubes

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

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

$$Xd=\left[\frac{q}{\tau\,\gamma''}\,\frac{\sqrt{\frac{\sigma}{\gamma'-\gamma''}}}{\nu'}\right]^{-0{,}125} Pr_{\ell}^{-0{,}5}\left(\frac{\mu'}{\mu''}\right)^{-0{,}2}\left(\frac{d}{\sqrt{\frac{\sigma}{\gamma'-\gamma''}}}\right)^{0{,}2}\left(\frac{500}{Re_{\ell}\frac{\gamma''}{\gamma'}+350}+0{,}35\right)$$

where Rel $= \dfrac{G\left(1-X_{av}\right)}{\gamma'\,u\,\nu'}$

Symbol	Definition	Units
Xd	Burnout steam quality	Dimensionless
q	Burnout heat flux	$Kcal/m^2$ hr
τ	Latent heat of vaporization	kcal/kg
γ', γ''	Liquid or steam density	kg/m^3
σ	Surface tension	kg/m
ν'	Liquid **kinematic** viscosity	m^2/hr
Pr_e	Liquid Prandtl's number	Dimensionless
μ', μ''	Liquid or steam viscosity	kg hr/m^2
d	Diameter	m
G	Total mass flow rate	kg/hr
u	Perimeter	m
X_{av}	Not defined in the translation	Dimensionless

R. A. Rybin

Critical Thermal loads During the boiling of a saturated liquid in tube. Atomnaya Energya - 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 :

$$K = \frac{q_{cr}}{r\sqrt{g\gamma''}\ \sqrt[4]{\sigma(\gamma'-\gamma'')}} = K_0\left(1-n\beta\right)$$

Symbol	Definition	Units
q_{cr}	Burnout Heat Flux	kcal/m^2-hour
r	Latent heat of vaporization	kcal/kg
g	Gravity Acceleration	m/$hour^2$
γ'	Liquid density at T_{sat}	kg/m^3
γ''	Steam density at T_{sat}	kg/m^3
T_{sat}	Saturation Temperature	°C
σ	Surface Tension	kg/m
K_0	Value of K when $\beta=0$ (2)	
n	Constant dependent on K_W (1)	
β	Volume flow rate quality	Dimensionless
K_W	Constant dependent on W_0 and P (3)	
W_0	$W_0 \cdot \gamma'$ mass velocity	Kg/m^2-hour
P	Pressure	kg/m^2

(1) $n = 0.08\ K_W^{0,55}$

(2) when $14 \leq K_w \leq 50$ $K_Q = 0{,}0575\ K_w^{0{,}25}$

when $50 \leq K_w \leq 80$ $K_o = 0{,}0145\ K_w^{0{,}6}$

(3) $K_w = W_o \sqrt[4]{\dfrac{\gamma' - \gamma''}{g^2 \sigma}}$

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 (1)

$$\phi_{BO}^{m}\, G^{n} = \frac{1 - X_{BO}}{a + X_{BO}}\, K$$

Symbol	Definition	Units
ϕ_{BO}	Burnout Heat Flux	watt/cm^2
G	Mass velocity	g/cm^2 sec
D	Hydraulic Equivalent Diameter	cm
L	Channel length	cm
X_{BO}	Burnout Steam Quality	Dimensionless number %
a	Ratio between specific volume of liquid and specific volume change upon vaporization : V_l/V_{gl}	Dimensionless number %
V_l	Specific Volume of liquid	cm^3/g
V_{gl}	Specific Volume change upon vaporization	cm^3/g
K	Constant dependent on pressure and L/D equal to $14150/(L/D)^{0,39}$ for P=70 ata	

n Constant dependent on the Pressure [2]

m Constant dependent on the Pressure [2]

p Pressure ata

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

$$\frac{1 - X_{BO}}{a + X_{BO}} \qquad \frac{K}{(L/D)^{1/3}} = G\phi_{BO}^{1/2} \qquad \text{with } K = 11\,000$$

in the case of non uniform heat flux distribution

$$\phi_{BO} = \frac{1}{L}\int_0^L \phi \, dL$$

(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 1000psia, is given for an uniform heat flux distribution in round tubes, and has the following form:

$$\phi = 0{,}45\left(1+\frac{0{,}546}{G}\right)\left(\frac{H_{Bo}}{10^3}\right)^{-2}\frac{\exp\left[-0{,}00165\ L/D\right]}{0{,}77+D}$$

Symbol	Definition	Units
ϕ	Burnout Heat Flux	10^6 Btu/ft^2-hour
G	Mass Velocity	10^6 lb/ft^2-hour
H_{Bo}	Burnout Enthalpy	Btu/lb
D	Diameter	in
L	Channel Length	in

R. V.Macbeth

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

$$\phi/10^6 = y_0 D^{y_1}\left(\frac{G}{10^6}\right)^{y_2} - \frac{1}{4} y_3 D^{y_4+1}\left(\frac{G}{10^6}\right)^{y_5+1}\lambda W$$

Rectangular channels with bilateral heating

$$\phi/10^6 = y_0' s^{y_1'}\left(\frac{G}{10^6}\right)^{y_2'} - 0{,}555\, y_3' s^{y_4'+1}\left(\frac{G}{10^6}\right)^{y_5'+1}\lambda W$$

2)

Low velocity

Round channels

$$\phi/10^6 = \frac{\lambda}{135}\left(\frac{G}{10^6}\right)^{1/2}\left(1 - W\right)$$

Rectangular channels

$$\phi/10^6 = \frac{\left(\frac{G}{10^6}\right)\left(\lambda + \Delta H_i\right)}{3{,}78\ S^{-1{,}73}\left(\frac{G}{10^6}\right)^{1{,}1} + \frac{1{,}8\ L}{S}}$$

Symbol	Definition	Units
ϕ	Burnout Heat Flux	Btu/ft^2-hour
G	Mass velocity	lb/ft^2-hour
W	Average mass flow rate quality	lb/lb
λ	Latent heat of vaporization	Btu/lb
D	Internal tube Diameter	in.
S	Internal spacing between heating surfaces of rectangular channel	in.
ΔH_i	Subcooled Enthalphy at channel inlet	Btu/lb
L	Channel Lenght	in.
$y_0, y_I, y_2, y_3, y_4, y_5$ $y'_0, y'_I, y'_2, y'_3, y'_4, y'_5$	Constants dependent on the Pressure(I)	

(1) They can be obtained by Tables on pages 10 and 15 in the above mentioned references.

G. V. Alekseyev - B. A. Zenkevitch - V. I. Subbotin

Critical Heat Fluxes in Annular Channels
Teploenergetika Vol. 10 , No. 10 pages 72-75 October 1963

Critical Heat Fluxes in Annular Channels with Heat Supply from two sides. Inzh. Fizicheskaia 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 :

$$q_{cr} = q_o \left[1 + 1{,}41 \cdot 10^{-6} \left(\frac{\gamma''}{\gamma'} \right)^{0{,}731} W_g \, K_2 \right]$$

where $K_2 = \dfrac{i' - i_{out}}{r}$ for unilateral heating

$$K_2 = \frac{i' - i_{out}}{r} + \frac{3{,}6 \cdot 10^3 \, q \, f_2}{W_g \, r \, f_1}$$ for bilateral heating

Symbol	Definition	Units
q_{cr}	Burnout Heat Flux	$watt/m^2$
q_o	Critical heat flux at $X_e = 0$	$watt/m^2$
γ'	Liquid density at T_{sat}	kg/m^3
γ''	Steam density at T_{sat}	kg/m^3
i'	Saturation Enthalphy	kcal/kg

i_{out}	Outlet Enthalphy	Kcal/kg
r	Latent heat of vaporization	Kcal/kg
q	Specific heat flux from the surface at which no crisis is expected	watt/m^2
f_1	Cross sectional are of channel	m^2
f_2	Area of the surface from which q is removed	m^2
W_g	Mass velocity	kg/m^2-hour
L	Length	m

(1) $$q_o = 0{,}611 \cdot 10^{-3}\, r^{1{,}58}\, L^{-0{,}262}$$

B. Thompson–R. V. Macbeth

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 :

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

$$A' = y_0 \, D^{y_1} (G \, 10^{-6})^{y_2} \left[1 + y_3 \, D + y_4 (G \, 10^{-6}) + y_5 \, D (G \, 10^{-6}) \right]$$

$$C' = y_6 D^{y_7} (G \, 10^{-6})^{y_8} \left[1 + y_9 \, D + y_{10} (G \, 10^{-6}) + y_{11} \, D (G \, 10^{-6}) \right]$$

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.

Symbol	Definition	Units
D	Internal tube diameter	in.
G	Average mass velocity	$lb/hr \, ft^2$
W	Quality at position of burnou.	Dimensionless

y_o to y_{11}	Numerical values optimized by the computer	Dimensionless
λ	Latent heat at system pressure	Btu/lb
ϕ	Burnout heat flux	Btu/hr ft^2

F. E. Tippets

Analysis of the critical Heat-Flux condition in High - Pressure Boiling water flows.
Journal of Heat Transfer - pages 23-38 February 1964

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

$$q_c = C'' \frac{\psi^m}{\zeta}$$

with $\psi = \dfrac{\sigma \rho_L (1+\rho_L/\rho_g)}{\phi_{TPF} f_F G^2 b \left(1+\sqrt{\rho_L/\rho_g}\right)^2}$ $\zeta = \dfrac{1+\left(1+C' \dfrac{X_c}{1-X_c}\right)\dfrac{\rho_L}{\rho_g}}{\left(\dfrac{\rho_L}{\rho_g}\phi_{TPF} f_F\right)^{1/2} G\, h_{fg}}$ $C'' = K'\left(2K_3K_4\right)^m/\sqrt{2}$

Symbol	Definition	Units
q_c	Burnout Heat Flux	Btu/ft^2-sec
C' and C''	Empirical constants	Dimensionless
m	Empirical constant	Dimensionless
σ	Surface Tension	lbm/sec^2
ρ_L	Liquid Density	lbm/ft^3
ρ_g	Vapor Density	lbm/ft^3
ϕ_{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	Burnout Steam Quality	Dimensionless
h_{fg}	Latent heat of vaporization	Btu/lbm
$K_1, K_2, K_3, K_4, K_5, K'$	Numerical constants	Dimensionless

B. A. Zenkevitch - G. V. Aleksyev et al.

Burnout Heat Fluxes under Forced water flow

Geneva Conference - A/Conf. 28/P/327 a May 1964

There are two correlations (1), given for an uniform heat flux distribution and for round ducts, with the following forms

$$1)\quad q_{BO} = 46{,}5\, W_g^{n} (1-X)^{m} \left(\frac{\gamma'}{\gamma''}\right)^{2,2} \left(1 + \frac{8 \cdot 10^{9}}{W_g^{K}}\right) \frac{2{,}71}{d_{in}^{0{,}48}}$$

$$2)\quad q_{BO} = \left[1{,}46 \cdot 10^{-4} r^{1{,}72} (1-X)^{m'} - 0{,}116\, W_g\right] \frac{2{,}71}{d_{in}^{0{,}48}}$$

Symbol	Definition	Units
q_{BO}	Burnout Heat Flux	watt/m^2
W_g	Mass Velocity	kg/m^2-h
X	Burnout Steam Quality	Dimensionless
γ'	Liquid Density at T_{sat}	kg/m^3
γ''	Steam Density at T_{sat}	kg/m^3
d_{in}	Diameter	mm
n, m, m'	Constant dependent on the Pressure (2)	
K	Constant dependent on the Pressure and on the Steam Quality (3)	
r	Latent heat of vaporization	j/kg

(1) The first correlation is valid for high Pressures ($100-200\ kg/cm^2$), the second for the Pressure Range : $40-100\ kg/cm^2$

(2) $n = 0{,}56 - 0{,}0189\ \gamma'/\gamma''$ $\quad m = 0{,}7\ \gamma'/\gamma'' - 0{,}4$ $\quad m' = 3{,}48 - 0{,}54\left(\frac{r}{4{,}18 \cdot 10^6}\right)$

(3) $K = 1{,}13 + 3{,}6\ \gamma''/\gamma' - 0{,}45\ X$

H. S. Tong - H. B. Currin - F. C. Engel

DNB studies in an open lattice core: WCAP 3736 August 1964

New Correlations Predict DNB Conditions Nucleonics 21,5,1963

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:

$$H_{DNB} - H_{in} = 0{,}529\left(H_f - H_{in}\right) + H_{fg}\left\{\left(0{,}825 + 2{,}36\, e^{-17 D_e}\right) e^{-1{,}5\, G/10^6} - 0{,}41\, e^{-0{,}0048\, L/D} - 1{,}12\, \frac{\rho_g}{\rho_L} + 0{,}548\right\}$$

Symbol	Definition	Units
H_{DNB}	Burnout Enthalphy	Btu/lb
H_{in}	Inlet Enthalphy	Btu/lb
H_f	Saturation Enthalphy	Btu/lb
H_{fg}	Enthalphy change from saturated liquid to saturated vapor	Btu/lb
D_e	Hydraulic Equivalent Diameter	in.
G	Mass Velocity	lb $/ft^2$-hour
L	Length	in.
ρ_g	Vapor Density	lb $/ft^3$
ρ_L	Liquid Density	lb $/ft^3$

S. Bertoletti - G. P. Gaspari - C. Lombardi

G. Peterlongo - M. Silvestri - F. A. Tacconi

A General correlation for predicting the heat transfer crisis with steam-water mixtures. Energia Nucleare - Vol. 11, No. 10 pages 586-597 October 1964

Heat Transfer crisis with steam-water mixtures. Energia Nucleare - Vol. 12, No. 3 pages 121-172 March 1965

The correlation, given for an uniform and non uniform (1) heat flux distribution, for round, rectangular channels and for clusters (2) has the following form :

$$\frac{\hat{W}_{si}}{\Gamma H_{ge}} = a_i \frac{L_s}{L_s + b}$$

Symbol	Definition	Units
$\hat{W}_{si}$	Total critical power input over L_s to surface i where the crisis sets on.	watt/cm^2
Γ	Mass Flowrate	g/sec
H_{ge}	Enthalphy change upon vaporization	J/g
a_i	Constant dependent on the Pressure and mass velocity (3)	
b	Constant dependent on the Pressure, mass velocity and diameter (4)	
L_s	Saturation length	cm
G	Mass velocity	g/cm^2-sec
P	Pressure	ata

D	Hydraulic Equivalent Diameter	cm
P_{crit}	Critical Pressure	ata

(1) $$\phi_{max} / \bar{\phi} < 4$$

(2)- **For complex geometries** a_i must be multiplied by P_i / P_{tot} where p_i is the perimeter of the surface i, P_{tot} is the wetted perimeter.

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

(4) $$b = 0{,}315 \left(\frac{P_{cr}}{P} - 1 \right)^{0,4} D^{1,4} G \quad \left[\text{C.G.S units} \right]$$

G. F. Hewitt

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,

$$X_o = \frac{2{,}5\,\alpha}{1+\frac{G}{10^6}} \quad \frac{L_s}{L_s + 8{,}48\,\beta\,D^{8/5}\left(\frac{G}{10^6}\right)^{2/3}}$$

Symbol	Definition	Units
X_o	Burnout Steam Quality	Dimensionless number
G	Mass velocity	lb/ft^2-hour
D	Diameter	in.
L_s	Saturation length	ft.
α	Constant dependent on the Pressure(1)	
β	Constant dependent on the Pressure(1)	
P	Pressure	ata

(1) $\alpha = \alpha(P)$ and $\beta = \beta(P)$ can be obtained by a simple expression which relate mathematically same experimental diagrams.

V. N. Smolin - B. K. Polyakov - V. l. Esikov

An experimental Investigation of Heat Transfer crisis
Journal of Nuclear Energy - Vol. 19 , No. 3 pages 209-216
March 1965

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_g) :

$$q_{cr} = \frac{2{,}41\ 10^9}{r\ \lambda\ \gamma''}\ A T_{sat} \left(\gamma' - \gamma''\right) \left(\frac{Re_{mix}}{Re_o^{1{,}15}}\right)^3 Pr^2 \left(\frac{\sqrt{\frac{\sigma}{\gamma' - \gamma''}}}{d}\right)^{0{,}5} \left(\frac{\gamma'}{\gamma''}\right)^2$$

Symbol	Definition	Units
q_{cr}	Burnout Heat Flux	kcal/m^2-hour
r	Latent heat of vaporization	kcal/kg
λ	Thermal conductivity	kcal/m-°C- hour
A	Heat Equivalent of mechanical work	kcal/kg
T_{sat}	Saturation Temperature	°C
γ', γ''	Liquid and Steam density	kg/m^3
Re_{mix}	Reynold's number for the mixture	Adimensional
Re_o	Reynold's number for the liquid	Adimensional
Pr	Prandtl's number	Adimensional
σ	Surface Tension	kg/m
d	Diameter	m

K. M. Becker - P. Persson

An analysis of Burnout conditions for flow of boiling water in vertical Round Duct - Journal of Heat Transfer pages 513-530 November 1964

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

$$B = \frac{-\lg\left(1-X_{bo}\right)+\lg\left(0{,}98-\frac{\varepsilon V B^{1/2}}{X_{bo}^{1/4}(B+1)}\right)-\lg\left(1-\frac{\varepsilon\left(X_{bo}+\gamma\right)B^{1/2}}{\left(1-X_{bo}\right)X_{bo}^{1/4}(B+1)}\right)}{\lg\frac{X_{bo}+\gamma}{\gamma}} = \frac{b\,h_{fg}}{V_{fg}}\,\frac{1}{\left(\frac{\dot{m}}{F}\right)^{1/2}\left(\frac{q}{A}\right)}$$

Symbol	Definition	Units
B	Ratio between the droplet transfer coefficient and boiling velocity	Dimensionless
K_g	Droplet transfer coefficient	m/sec
V_b	Boiling Velocity	m/sec
X_{bo}	Burnout Steam Quality	Dimensionless
ε	Reentrainment coefficient	Dimensionless
γ	Ratio between the specific volume of the liquid and the specific volume change upon vaporization	
V_f	Specific volume of the liquid	m^3/kg
V_{fg}	Specific volume change upon vaporization	m^3/kg
b	Droplet diffusion coefficient	$kg^{1/2}/sec^{2/3}$
h_{fg}	Latent heat of vaporization	kj/kg

$\dot{m}/F$	Mass velocity	kg/m^2 sec
q/A	Burnout Heat Flux	kj/m^2-sec

K. M. Becker

An accurate and simple correlation for Burnout conditions in vertical Round Ducts AE - RTL - 798 June 1965

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

$$X_{bo} = a_o \left(\frac{10^5}{G^{0,5}\, q/A} - a_1 \right)$$

Symbol	Definition	Units
X_{bo}	Burnout Steam Quality	Adimensional
G	Mass Velocity	kg/m^2-sec
q/A	Burnout Heat Flux	kj/m^2-sec
a_o	Constant dependent on the Pressure (1)	
a_1	Constant dependent on the Pressure (1)	
P	Pressure	kg/cm^2

(1) $a_o = a_o(P)$ 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

$$\phi_o = 171 \frac{H_{Lg} \quad K}{D^{1/4}} \left(\frac{135{,}6}{G} \right)^n \left(\frac{1 - X_o}{X_o + v} \right) \quad \text{watt/cm}^2$$

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

$$n = n(P) \approx -3{,}25 \cdot 10^{-4} P^2 + 5{,}57 \; 10^{-2} P - 0{,}835$$

$$K = K(P) \approx 1{,}73 \cdot 10^{-3} - 8{,}3 \cdot 10^{-6} P$$

Range of validity for the involved parameters

G	$27 \leq G \leq 420$	g/cm^2 sec
P	$35 \leq P \leq 140$	ata
D	$0.25 \leq D \leq 0.50$	cm
L	L not given	

L/D $\quad 33 \le L/D \le 240$

X_o $\quad 0.15 \le X_o \le 0.80$

X_{in} $\quad X_{in} < 0$

ϕ_o $\quad 63 \le \phi_o \le 630 \quad$ watt/cm^2

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

$$X_o \longrightarrow 0 \qquad \phi_o \longrightarrow 171 \frac{H_{Lg}\ K}{D^{1/4}} \left(\frac{135{,}6}{G} \right)^n \frac{1}{v}$$

$$X_o \longrightarrow 1 \qquad \phi_o \longrightarrow 0$$

$$P \longrightarrow P_{crit} \qquad \phi_o \longrightarrow 0$$

$$G \longrightarrow 0 \qquad \phi_o \longrightarrow \infty$$

$$G \longrightarrow \infty \qquad \phi_o \longrightarrow 0$$

The correlation does not depend on L

A. A. Ivashkevitch

Standard Form

There are two correlations, of which the first one is valid for $D/2 > \left[\frac{\sigma}{g(\rho_L - \rho_g)}\right]^{1/2}$ the second one for $D/2 < \left[\frac{\sigma}{g(\rho_L - \rho_g)}\right]^{1/2}$

1st Standard form

$$1)\quad \phi_0 = \frac{G H_{Lg}}{4} \cdot \frac{4 f(P)(1 - X_0) - 1{,}8 \cdot 10^{-6} G X_0}{\mu_L \left[g(\rho_L - \rho_g)/\sigma\right]^{1/2} + 9 \cdot 10^{-5} G} \quad \text{watt/cm}^2$$

$$2)\quad \phi_0 = \frac{G H_{Lg} f(P)(1 - X_0)}{\mu_L \left[g(\rho_L - \rho_g)/\sigma\right]^{1/2} + 3{,}15 \cdot 10^{-4} G} \quad \text{watt/cm}^2$$

2nd Standard form

$$1)'\quad \phi_0 = \frac{G H_{Lg} D}{4} \cdot \frac{4 f(P)(1 - X_0) - 1{,}8 \cdot 10^{-6} G X_0}{2\mu_L + 9 \cdot 10^{-5} G D} \quad \text{watt/cm}^2$$

$$2)' \quad \phi_o = \frac{H_{Lg}\, G \cdot D\, f(P)\,(1 - X_o)}{2\mu_L + 3{,}15 \cdot 10^{-4}\, G\, D} \qquad \text{watt}/\text{cm}^2$$

The forms 1) and 1)' must be used at low quality $\frac{H_{Lg}\, G\, X_o}{4\,\phi_o} \leq 12$

The forms 2) and 2)' must be used at high quality $\frac{H_{Lg}\, G\, X_o}{4\,\phi_o} > 125$

f(P) is a constant dependent on the pressure:

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

Range of validity for the involved parameters

G	$15 \leq G \leq 325$	g/cm^2 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_0	$0 < X_o < 1$	
X_{in}	$-0{,}8 < X_{in} < 0$	
ϕ_o	ϕ_o not given	

This range of validity is given by the author

Asymptotic Trend

$$X_o \longrightarrow 0 \quad \begin{cases} \phi_o^{(1)} \longrightarrow \dfrac{G\, H_{Lg}\, F(P)}{\mu_L \left[g(\rho_L - \rho_g)/\sigma \right]^{1/2} + 9 \cdot 10^{-5}\, G} \\ \phi_o^{(1)'} \longrightarrow \dfrac{D\; G\; H_{Lg}\; F(P)}{2\mu_L + 9 \cdot 10^{-5}\; G\, D} \end{cases}$$

$$X_o \longrightarrow 1 \quad \begin{cases} \phi_o^{(2)} \longrightarrow 0 \\ \phi_o^{(2)'} \longrightarrow 0 \end{cases}$$

$$P \longrightarrow P_{crit} \quad \begin{cases} \phi_o^{(1)(1)'} \longrightarrow 0 \\ \phi_o^{(2)(2)'} \longrightarrow 0 \end{cases}$$

$$G \longrightarrow 0 \quad \begin{cases} \phi_o^{(1)(1)'} \longrightarrow 0 \\ \phi_o^{(2)(2)'} \longrightarrow 0 \end{cases}$$

$$G \longrightarrow \infty \begin{cases} \phi_o^{(1)(1)'} \longrightarrow -\infty \\ \phi_o^{(2)(2)'} \longrightarrow \dfrac{H_{eq}\, f(P)\,(1-X_o)}{3{,}15 \cdot 10^{-4}} \end{cases}$$

The correlation does not depend on L

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

L. Miropol'skii - Shitsman - Faktorovich

Standard form

$$\phi_0 = c_1 H_{Lg}^{0,2} \left(\frac{\sigma \rho_L}{\mu_L} \right)^{0,6} \left(\frac{\rho_L}{\rho_g} \right)^{0,08} \left(c_L(\theta+273) \right)^{0,8} \left(1 - X_0\right)^n G^{0,4} \quad \text{watt/cm}^2$$

where:

c_1 is a constant dependent on the geometry and on the ratio L/D.

c_1

- Round and annular ducts
  - $4.83 \; 10^{-5}$ when $L/D > 100$
  - $4.83 \; 10^{-5}$ when $L/D < 100$
- Rectangular Channels
  - $6.22 \; 10^{-5}$ when $L/D > 100$
  - $6.22 \; 10^{-5}$ when $L/D < 100$

c_1^* is the smaller value between $e^{0,0122(100-L/D)}$ and $0,373 \left[\frac{G \mu_L}{\sigma \rho_L} \left(\frac{\rho_L}{\rho_g} \right)^{0,2} \left(1 - X_0\right)^{2,5n} \right]^{-0,4}$

n is a constant dependent on the geometry, on G and P :

$$
n = \begin{cases}
\text{Round and Annular ducts} & \begin{cases}
0{,}8 & \text{when } \dfrac{G\,\mu_L}{\sigma\,\rho_L}\left(\dfrac{\rho_L}{\rho_g}\right)^{0,2} < 1{,}6\cdot10^{-2} \\[2ex]
50\,\dfrac{G\,\mu_L}{\sigma\,\rho_L}\left(\dfrac{\rho_L}{\rho_g}\right)^{0,2} & \text{when } 1{,}6\cdot10^{-2} < \dfrac{G\,\mu_L}{\sigma\,\rho_L}\left(\dfrac{\rho_L}{\rho_g}\right)^{0,2} < 6\cdot10^{-2} \\[2ex]
3 & \text{when } \dfrac{G\,\mu_L}{\sigma\,\rho_L}\left(\dfrac{\rho_L}{\rho_g}\right)^{0,2} > 6\cdot10^{-2}
\end{cases} \\[8ex]
\text{Rectangular Channels} & \begin{cases}
33{,}3\,\dfrac{G\,\mu_L}{\sigma\,\rho_L}\left(\dfrac{\rho_L}{\rho_g}\right)^{0,2} & \text{when } 2\cdot10^{-2} \leq \dfrac{G\,\mu_L}{\sigma\,\rho_L}\left(\dfrac{\rho_L}{\rho_g}\right)^{0,2} \leq 9\cdot10^{-2} \\[2ex]
3 & \text{when } \dfrac{G\,\mu_L}{\sigma\,\rho_L}\left(\dfrac{\rho_L}{\rho_g}\right)^{0,2} > 9\cdot10^{-2}
\end{cases}
\end{cases}
$$

Range of validity for the involved parameters

G^{*}	$20 \leq G \leq 1000$	g/cm^2 sec
P^{*}	$20 \leq P \leq 200$	ata
D^{*}	$\begin{cases} D > 0.4 \\ \delta < 0.13 \end{cases}$	cm cm
L^{***}	L	not given
L/D^{***}	L/D	not given

X_o $\qquad$ $X_o \gtrsim 0{,}97 - 3{,}6 \cdot 10^{-3} P$

X_{in} $\qquad$ corresponding to $\Delta T_{sub} < 150\ °C$

ϕ_o $\qquad$ ϕ_o not given

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

** $\delta > 0.13$ cm is referred to annular ducts.

*** The authors have not given restrictions on L and L/D and ϕ_o

Asymptotic Trend

$X_o \longrightarrow 0$ $\qquad$ $\phi_o \longrightarrow C_1 H_{Lg}^{0,2} \left(\frac{\sigma \rho_L}{\mu_L}\right)^{0,6} \left(\frac{\rho_L}{\rho_g}\right)^{0,08} \left(c_L(\theta+273)\right)^{0,8} \cdot G^{0,4}$

$X_o \longrightarrow 1$ $\qquad$ $\phi_o \longrightarrow 0$

$P \longrightarrow P_{crit}$ $\qquad$ $\phi_o \longrightarrow 0$

$G \longrightarrow 0$ $\qquad$ $\phi_o \longrightarrow 0$

$$G \longrightarrow \infty \qquad\qquad \phi_o \longrightarrow \infty$$

when D is fixed and L increases, ϕ_0 increases with L and reaches the saturation for L/D equal to 100.

Standard Form

$$\phi_o = 0{,}7323\, H_{Lg} \left\{ \sigma \rho_L^3 \frac{\gamma^2}{(1+\gamma)^3} \right\}^{1/4} + 0{,}18\, \frac{K_L}{D} \left(\frac{G\,D}{\mu_L} \right)^{0{,}8} \left(\frac{\mu_L\, C_L}{K_L} \right)^{0{,}33} \phi_o^{1/4} \exp\left(- P/63{,}3 \right) +$$

$$- 0{,}695955\, H_{Lg}\, \beta'^2 \gamma \left[\frac{\rho_L}{\sigma (1+\gamma)} \right]^{1/4} \left(10^5 \mu_L \right)^{1/3} G^{2/3} D^{1/6} \quad \text{watt/cm}^2$$

where β' 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 ata $\begin{cases} X_o = 0{,}05 \\ 0{,}1 \leq X_o \leq 1 \end{cases}$ $\quad$ $\begin{matrix} \beta' = 0{,}10 \\ \beta' = 0{,}11 + 0{,}46\, X_o \end{matrix}$

P = 71 ata $\begin{cases} X_o = 0{,}05 \\ 0{,}1 \leq X_o \leq 1 \end{cases}$ $\quad$ $\begin{matrix} \beta' = 0{,}07 \\ \beta' = 0{,}07 + 0{,}4\, X_o \end{matrix}$

P = 84 ata $\begin{cases} X_o = 0{,}05 \\ 0{,}1 \leq X_o \leq 1 \end{cases}$ $\quad$ $\begin{matrix} \beta' = 0{,}06 \\ \beta' = 0{,}06 + 0{,}370\, X_o \end{matrix}$

$$P = 142 \text{ ata} \begin{cases} 0 < X_o \leq 0{,}3 & \beta' = 0{,}533\, X_o \\ 0{,}3 \leq X_o \leq 1 & \beta' = 0{,}09 + 0{,}233\, X_o \end{cases}$$

Rectangular ducts

$$P = 42 \text{ ata} \begin{cases} X_o = 0{,}05 & \beta' = 0{,}08 \\ 0{,}1 \leq X_o < 1 & \beta' = 0{,}12 + 0{,}3\, X_o \end{cases}$$

$$P = 71 \text{ ata} \begin{cases} X_o = 0{,}05 & \beta' = 0{,}065 \\ 0{,}1 \leq X_o < 1 & \beta' = 0{,}067 + 0{,}338\, X_o \end{cases}$$

$$P = 84 \text{ ata} \begin{cases} X_o = 0{,}05 & \beta' = 0{,}04 \\ 0{,}1 \leq X_o < 1 & \beta' = 0{,}06 + 0{,}33\, X_o \end{cases}$$

$$P = 142 \text{ ata} \begin{cases} X_o = 0{,}05 & \beta' = 0{,}03 \\ 0{,}1 \leq X_o < 1 & \beta' = 0{,}045 + 0{,}28\, X_o \end{cases}$$

Range of validity for the involved parameters

G	$20 \leq G \leq 380$	g/cm^2 sec
P	$42 \leq P \leq 140$	ata
D	$0.13 \leq D \leq 0.46$	cm
L	$30 \leq L \leq 81$	cm

L/D	$L/D \geq 60$
X_e	$X_e > 0$
X_{in}	$X_{in} < 0$
ϕ_o	ϕ_o not given

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

Asymptotic Trend

$X_e \longrightarrow 0$ $\quad \phi_o \rightarrow 0{,}7323\, H_{Lg}\left[\sigma \rho_L^3 \frac{\gamma^2}{(1+\gamma)^3}\right]^{1/4} + 0{,}18\, \frac{K_L}{D}\left|\frac{G\,D}{\mu_L}\right|^{0{,}8}\left|\frac{\mu_L C_L}{K_L}\right|^{0{,}33} \phi_o^{1/4} \exp(-P/63{,}3)$

$X_e \longrightarrow 1$ $\quad$ to negative values

$P \longrightarrow P_{crit}$ $\quad \phi_o \longrightarrow 0.18\, \frac{K_L}{D}\left(\frac{G\,D}{\mu_L}\right)^{0{,}8}\left(\frac{\mu_L C_L}{K_L}\right)^{0{,}33} \phi_o^{1/4} \exp\left(-P_{crit}/63{,}3\right)$

where all the parameters are calculated in correspondence of $P = P_{crit}$

$G \longrightarrow 0$ $\quad \phi_o \longrightarrow 0{,}7323\, H_{Lg}\left\{\sigma \rho_L^3 \frac{\gamma^2}{(1+\gamma)^3}\right\}^{1/4}$

$G \longrightarrow \infty$ $\quad \phi_o \longrightarrow \infty$

The correlation does not depend on L.

Standard Form

$$\phi_o = \frac{H_{eg}}{X_o^{8}} \frac{D^{8/5}}{P_r^{4}} \left[\frac{\mu_e \rho_g}{\rho_e} \left(\frac{g(\rho_e - \rho_g)}{\sigma} \right)^{1/2} \right] \left[\frac{\mu_g}{\mu_e \left(\frac{\sigma}{g(\rho_e - \rho_g)} \right)^{1/2}} \right]^{8/5} \left[\frac{0.35\, DG(1-X_o) + 2492\, \mu_e \rho_e/\rho_g}{DG(1-X_o) + 1400\, \mu_e \rho_e/\rho_g} \right]$$

watt/cm²

Range of validity for the involved parameters

G	$10 \leq G \leq 1320$	g/cm² sec
P	$20 \leq P \leq 200$	ata
D	$0.4 \leq D \leq 3.22$	cm.
L	$150 \leq L \leq 300$	cm.
L/D	$93 \leq L/D \leq 375$	
X_o	$X_o > 0.1$	
X_{in}	$X_{in} < 0$	
ϕ_o	$10 \leq \phi_o \leq 390$	watt/cm².

This range of validity is given by the authors.

(1) Assuming $X_{av} = X_o$

Asymptotic Trend

$X_o \longrightarrow 0$ $\quad\quad$ $\phi_o \longrightarrow \infty$

$X_o \longrightarrow 1 \qquad \phi_o \longrightarrow \dfrac{H_{eg}\, D^{8/5}}{P_r^{\,4}} \left\{ \dfrac{\mu_e\ \rho_g}{\rho_e} \left[g \dfrac{(\rho_e - \rho_g)}{\sigma} \right]^{1/2} \right\} \left[\dfrac{\mu_g}{\mu_e \left(\dfrac{\sigma}{g(\rho_e - \rho_g)} \right)^{1/2}} \right]^{8/5} \left(\dfrac{2492}{1400} \right)^{8}$

$P \longrightarrow P_{crit} \qquad \phi_o \longrightarrow 0$

$G \longrightarrow 0 \qquad$ idem as for $X_o \longrightarrow 1$

$G \longrightarrow \infty \qquad \phi_o \longrightarrow \dfrac{H_{eg}}{X_o^{8}} \dfrac{D^{8/5}}{P_r^{\,4}} \left(\dfrac{\mu_e\ \rho_g}{\rho_e} \left[\dfrac{g(\rho_g - \rho_e)}{\sigma} \right]^{1/2} \right) \left[\dfrac{\mu_g}{\mu_e \left(\dfrac{\sigma}{g(\rho_e - \rho_g)} \right)^{1/2}} \right]^{8/5} (0{,}35)^{8}$

Rybin

Standard Form

$$\phi_o = H_{Lg}\, \rho_g^{1/2} \left\{ g\,\sigma \left(\rho_e - \rho_g\right) \right\}^{1/4} K_o \frac{\nu + \left[1-(1+\nu)n\right] X_o}{\gamma + X_o} \quad \text{watt}/\text{cm}^2$$

where:

n and k_o are two constants dependent on the Pressure and mass velocity.

$$n = 0{,}08 \left\{ \frac{G}{\rho_L} \sqrt[4]{\frac{\rho_L - \rho_g}{g\,\sigma}} \right\}^{0{,}55}$$

$$K_o \begin{cases} 0{,}0575 \left\{ \dfrac{G}{\rho_L} \sqrt[4]{\dfrac{\rho_L - \rho_g}{g\,\sigma}} \right\}^{0{,}25} & \text{when } 14 < \dfrac{G}{\rho_L} \sqrt[4]{\dfrac{\rho_L - \rho_g}{g\,\sigma}} \leq 50 \\ 0{,}01450 \left\{ \dfrac{G}{\rho_L} \sqrt[4]{\dfrac{\rho_L - \rho_g}{g\,\sigma}} \right\}^{0{,}6} & \text{when } 50 < \dfrac{G}{\rho_L} \sqrt[4]{\dfrac{\rho_L - \rho_g}{g\,\sigma}} < 80 \end{cases}$$

Range of validity for the involved parameters.

G	$80 \leq G \leq 700$	g/cm^2 sec
P	$70 \leq P \leq 206$	ata
D	$D > 0.6$	cm
L	L	not given
L/D	L/D	not given
X_o	$0 < X_o < \dfrac{0{,}85\,\rho_g/\rho_L}{0{,}15 + 0{,}85\,\rho_g/\rho_L}$	
X_{in}	$X_{in} < 0$	
ϕ_o	$65 \leq \phi_o \leq 450$	$watt/cm^2$

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

Asymptotic Trend

$X_o \longrightarrow 0$ $\qquad \phi_o \longrightarrow H_{Lg}\,\rho_g^{1/2}\left\{g\,\sigma\left(\rho_L - \rho_g\right)\right\}^{1/4} K_o$

$X_o \longrightarrow 1$ $\qquad \phi_o \longrightarrow H_{Lg}\,\rho_g^{1/2}\left\{g\,\sigma\left(\rho_L - \rho_g\right)\right\}^{1/4} K_o\left(1 - n\right)$

$P \longrightarrow P_{crit}$ $\qquad \phi_o \longrightarrow 0$

$$\left.\begin{array}{l} G \longrightarrow 0 \\ \\ G \longrightarrow \infty \end{array}\right\}$$

For these values of G K_e 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 the pressure of 70 ata only and containing the dependence on the ratio L/D, is

$$\phi_o = \frac{121.10^6}{G^2}\left(\frac{L}{D}\right)^{-2/3}\left(\frac{1-X_o}{X_o+r}\right)^2 \; \mathrm{watt/cm^2}$$

The second form, valid for all pressures $\neq$ to 70 ata, is

$$\phi_o^m = K\ G^{-n}\frac{(1-X_o)}{(X_o+r)} \; \mathrm{watt/cm^2}$$

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:

$m = m(P) \approx -10^{-5}P^2 + 5.83\ 10^{-3}P + 0.12$

$n = n(P) \approx 1.3819 - 0.00459P$

$k = k(P) \approx 0.532P^2 - 88P + 6 \cdot 10^3$

Range of validity for the involved parameters

G	$100 \leq G \leq 450$	g/cm^2 sec
P	$45 \leq P \leq 85$	ata
D	$0.3 \leq D \leq 1$	cm.
L	$10 \leq L \leq 80$	cm.
L/D	$20 \leq L/D \leq 266$	
X_o	$X_o \leq X_{o\,lim}$ (+)	
X_{in}	$-0.05 \leq X_{in} \leq -0.7$	
ϕ_o	$10 \leq \phi_o \leq 500$	$watt/cm^2$

This range of validity is given by the authors.

(+) - $X_{o\,lim}$ is the value of X_o necessary in order to avoid the hydrodynamic perturbations effect.

Asymptotic Trend

$X_o \longrightarrow 0 \qquad \phi_o \longrightarrow K^{1/m} \quad G^{-n/m}\left(\frac{1}{Y}\right)^{1/m}$

$X_o \longrightarrow 1 \qquad \phi_o \longrightarrow 0$

$P \longrightarrow P_{crit} \qquad \phi_o \longrightarrow$ to value not defined because m and n are not defined.

$G \longrightarrow 0 \qquad \phi_o \longrightarrow \infty$

$G \longrightarrow \infty \qquad \phi_o \longrightarrow 0$

At 70 ata, ϕ_o decreases with L/D increasing.

D. H. Lee - J. D. Obertelli

Standard Form

$$\phi_0 = 360{,}5\left(\frac{10^3 \cdot 2{,}326}{H_{fg} X_0 + H_s}\right)^2 \left(1 + \frac{73{,}98}{G}\right) \frac{\exp\left(-0{,}00165\, L/D\right)}{1{,}955 + D} \quad \mathrm{watt}/\mathrm{cm}^2$$

Range of validity for the involved parameters

G	$102 \leq G \leq 225$	g/cm^2 sec
P	$P = 70$	ata
D	$0.56 \leq D \leq 1.15$	cm
L	$22 \leq L \leq 135$	cm
L/D	$39 \leq L/D \leq 360$	
X_0	$X_0 > 0$	
X_{in}	$-0.23 < X_{in} < 0$	
ϕ_0	ϕ_0	not given

This range of validity is given by the authors.

Asymptotic Trend

$$X_o \longrightarrow 0 \qquad \phi_o \longrightarrow \frac{1{,}95 \cdot 10^9}{H_s^2}\left(1+\frac{73{,}98}{G}\right)\frac{\exp\left(-0{,}00165\, L/D\right)}{1{,}955+D}$$

$$X_o \longrightarrow 1 \qquad \phi_o \longrightarrow 1{,}95\ \frac{10^9}{(H_{Lg}+H_s)^2}\left(1+\frac{73{,}98}{G}\right)\frac{\exp\left(-0{,}00165\, L/D\right)}{1{,}955+D}$$

$$P \longrightarrow P_{crit} \qquad \phi_o \longrightarrow \infty$$

$$G \longrightarrow \infty \qquad \phi_o \longrightarrow 1{,}95\ \frac{10^9}{(H_{Lg}\, X_o+H_s)^2}\ \frac{\exp\left(-0{,}00165\, L/D\right)}{1{,}955+D}$$

ϕ_o decreases with L/D.

Standard form

$$\phi_0 = H_{eg}\left(\frac{G}{135,6}\right)^{1/2}(1 - X_0)\ \text{watt/cm}^2$$

Range of validity for the involved parameters

G	$1.36 \leq G \leq 84$	g/cm^2 sec
P	$1.06 \leq P \leq 141$	ata
D	$0.304 \leq D \leq 0.99$	cm
L	$15.2 \leq L \leq 310$	cm
L/D	$L/D > 50$	
X_o	$0. < X_o < 1$	
X_{in}	$-1.31 < X_{in} < 0$	
ϕ_o	ϕ_o not given	

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

Asymptotic Trend

$X_0 \longrightarrow 0$ $\qquad \phi_0 \longrightarrow H_{eg}\left(\frac{G}{135{,}6}\right)^{1/2}$

$X \longrightarrow 1$ $\qquad \phi_0 \longrightarrow 0$

$P \longrightarrow P_{crit}$ $\qquad \phi_0 \longrightarrow 0$

$G \longrightarrow 0$ $\qquad \phi_0 \longrightarrow 0$

The correlation does not depend on L

R. V. Macbeth

Correlation forlow velocity and rectangular ducts

Standard Form

$$\phi_o = 11{,}66\, H_{Lg} \frac{\delta^{1{,}73}}{G^{0{,}1}} \left(1 - X_o\right) \quad \text{watt/cm}^2$$

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
	$0.13 \leq \delta \leq 0.256$	cm.
L	$15.2 \leq L \leq 64.8$	cm.
L/D	$60 \leq L/D \leq 460$	
X_o	$0 \leq X_o \leq 1$	
X_{in}	$-1.35 \leq X_{in} < 0$	
ϕ_o	ϕ_o not given	

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

$X_o \longrightarrow 0 \qquad \phi_o \longrightarrow 11.66\, H_{lg} \frac{\delta^{1{,}73}}{G^{0{,}1}}$

$X_o \longrightarrow 1 \qquad \phi_o \longrightarrow 0$

$P \longrightarrow P_{crit} \qquad \phi_o \longrightarrow 0$

$G \longrightarrow 0 \qquad \phi_o \longrightarrow \infty$

The correlation does not depend on L.

R. V. Macbeth

Correlation for High velocity and Round ducts

Standard Form

$$\Phi_0 = G\left\{2{,}325\, y_0 \left(\frac{D}{2{,}54}\right)^{y_1} \left(\frac{G}{135{,}6}\right)^{y_2-1} - 0{,}25\, y_3 H_{eg} \left(\frac{D}{2{,}54}\right)^{-0{,}4} \left(\frac{G}{135{,}6}\right)^{y_4} X_0\right\} \quad \mathrm{Watt/cm^2}$$

where the y_i 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	$0 < X_0 < 1$	
X_{in}	$-2.5 < X_{in} < 0$	
Φ_0	Φ_0 not given.	

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

Asymptotic Trend

$$X_0 \longrightarrow 0 \qquad \Phi_0 \longrightarrow G\left\{2{,}325\, y_0 \left(\frac{D}{2{,}54}\right)^{y_1} \left(\frac{G}{135{,}6}\right)^{y_2-1}\right\}$$

$$X_e \longrightarrow 1 \qquad \phi_0 \longrightarrow G\left\{2{,}325\, y_0 \left(\frac{D}{2{,}54}\right)^{y_1} \left(\frac{G}{135{,}6}\right)^{y_2-1} - 0{,}25\, y_3 H_{eg} \left(\frac{D}{2{,}54}\right)^{0{,}4} \left(\frac{G}{135{,}6}\right)^{y_4}\right\}$$

For $P \longrightarrow P_{crit}$ the asymptotic trend is not defined because the constants y_i are given for some particular pressures only.

$G \longrightarrow \infty \quad \phi_0 \longrightarrow \pm\infty$ 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

P:ata	y_1	y_2	y_3	y_4	y_0
1.05	-0.211	-0.324	+ 0.0010	-1.05	+1.12
17.5	-0.533	-0.260	+ 0.0166	-0.937	+1.77
37	-0.566	-0.329	+ 0.0127	-0.737	+1.57
70	-0.487	-0.179	+ 0.0085	-0.555	+1.06
110	-0.527	+0.024	+ 0.0121	-0.096	+0.720
140	-0.268	0.192	+ 0.0093	-0.343	+0.627
190	-1.45	+0.489	+ 0.0097	-0.529	+0.0124

R. V. Macbeth

Correlation for high velocity and rectangular ducts

Standard Form

$$\phi_o = G\left\{2{,}325\, y_o \left(\frac{\delta}{2{,}54}\right)^{y_1}\left(\frac{G}{135{,}6}\right)^{y_2-1} - 0{,}555\, H_{eg}\left(\frac{\delta}{2{,}54}\right)^{-0{,}4}_{y_3}\left(\frac{G}{135{,}6}\right)^{y_4} X_o\right\} \qquad \text{watt}/\text{cm}^2$$

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/δ	$60 \leq L/\delta \leq 460$	
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

$$X_o \longrightarrow 0 \qquad \phi_o \longrightarrow G\left\{2{,}325\, y_o\left(\frac{\delta}{2{,}54}\right)^{y_1}\left(\frac{G}{135{,}6}\right)^{y_2-1}\right\}$$

$X_o \longrightarrow 1 \quad \phi_o = G\left\{2{,}325\, y_o \left(\frac{\delta}{2{,}54}\right)^{y_1} \left(\frac{G}{135{,}6}\right)^{y_2 - 1} - 0{,}555\, H_{eg} \left(\frac{\delta}{2{,}54}\right)^{-0{,}4} Y_3 \left(\frac{G}{135{,}6}\right)^{y_4}\right\}$

For $P \longrightarrow P_{crit}$ the asymptotic trend is not defined because the constants y_i are given for some particular pressures only.

For $G \longrightarrow \infty$, $\phi_o \longrightarrow \pm \infty$ in correspondence with the values of y_i, whose values oscillate from negative values to positive ones.

The correlation does not depend on L.

Table II for the values of the constants y_i

P ata	y_o	y_1	y_2	y_3	y_4
43.7	+23.4	-0.472	-3.29	+0.123	-3.93
58.5	+0.445	-1.01	+0.384	+ 0.0096	-0.0067
88	+1.88	-0.081	-0.526	+ 0.0035	-1.29
146	+0.546	-0.315	-0.056	+ 0.0027	-0.725

Standard Form

$$\phi_o = 1{,}11 \cdot 10^{-2} \frac{H_{eg}^{1{,}58}}{L^{0{,}262}} \left\{ 1 - 5{,}07 \cdot 10^{-2} \left(\frac{\rho_g}{\rho_e} \right)^{0{,}731} G \left(X_o - X_e \right) \right\} \quad \text{watt/cm}^2$$

where X_e is a constant which is equal to 0 for unilateral internal heating and equal to $\dfrac{\phi_{NB}\ S_{RNB}}{G\,H_{eg}\ S_f}$ for bilateral internal heating.

ϕ_{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/cm^2. 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}	$X_{in} < 0$	
ϕ_o	ϕ_o not given	

This range of validity is given by the authors.

Asymptotic Trend

$X_e \longrightarrow 0 \qquad \phi_o \longrightarrow 1{,}11 \cdot 10^{-2} \cdot H_{eg}^{1{,}58} \cdot L^{-0{,}262} \left\{ 1 + 5{,}07 \cdot 10^{-2} \left(\frac{\rho_g}{\rho_e} \right)^{0{,}731} G \cdot X_e \right\}$

$X_e \longrightarrow 1 \qquad \phi_o \longrightarrow$ to value $\gtrless 0$ in correspondence of the values of G and P.

$P \longrightarrow P_{crit} \quad \phi_o \longrightarrow 0$

$G \longrightarrow 0 \qquad \phi_o \longrightarrow 1{,}11 \cdot 10^{-2} \dfrac{H_{eg}^{1{,}58}}{L^{0{,}262}}$

$G \longrightarrow \infty \quad \phi_o \longrightarrow \pm \infty$ when $X_e \gtrless X_o$

ϕ_o decreases monotonically with L.

B. A. Zenkevitch - G. V. Alekseyev 1st correlation

(High Pressure)

Standard Form

$$\phi_o = \frac{4{,}18\ 10^{-3}}{D^{0{,}48}} \left(G \cdot 3{,}6 \cdot 10^4\right)^n \left(\rho_L / \rho_g\right)^{2{,}2} \left[1 + \frac{8 \cdot 10^9}{\left(3{,}6 \cdot 10^4 G\right)^K}\right] \left(1 - X_o\right)^m \ \mathrm{watt/cm^2}$$

where :

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

$$m = m(P) = 0{,}7\ \rho_L / \rho_g - 0{,}4$$

$$n = n(P) = 0{,}56 - 0{,}0189\ \rho_L / \rho_g$$

$$K = K(P, X_o) = 1{,}13 + 3{,}6\ \rho_g / \rho_L - 0{,}45\, X_o$$

Range of validity for the involved parameters

G	$110 \leq G \leq 500$	g/cm^2 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	

X_o	$0 < X_o < 0.4$	
X_{in}	X'_{in}	not given
ϕ_o	ϕ_o	not given

This Range of validity is given by the authors.

Asymptotic Trend

$$X_o \longrightarrow 0 \qquad \phi_o \longrightarrow \frac{4.18 \cdot 10^{-3}}{D^{0,48}} \left(G \cdot 3,6 \cdot 10^4\right)^n \left(\rho_L / \rho_g\right)^{2,2} \left\{1 + \frac{8 \cdot 10^9}{\left(3,6 \cdot 10^4\, G\right)^K}\right\}$$

$$X_o \longrightarrow 1 \qquad \phi_o \longrightarrow 0$$

$$P \longrightarrow P_{crit} \qquad \phi_o \longrightarrow \frac{4.18 \cdot 10^{-3}}{D^{0,48}} \left(G\, 3,6 \cdot 10^4\right)^n \left(1 + \frac{8 \cdot 10^9}{\left(3,6 \cdot 10^4 G\right)^K}\right) \left(1 - X_o\right)^m$$

$$m \longrightarrow 0,3 \qquad n \longrightarrow 0,5411$$

$$K \longrightarrow 4,73 - 0,45\, X_o$$

$$G \longrightarrow 0 \qquad \phi_o \longrightarrow \infty$$

$$G \longrightarrow \infty \qquad \phi_o \longrightarrow 0$$

2nd correlation (Average Pressure)

Standard Form

$$\phi_o = \frac{0{,}376}{D^{0.48}}\left[5{,}1.10^{-3}\ H_{L_9}^{1.72}\,(1-X_o)^m - G\right] \qquad \text{watt/cm}^2$$

where m is a constant dependent on the Pressure.

$$m = m(P) = 3{,}48 - 1{,}29.10^{-4}\ H_{L_9}$$

Range of validity for the involved parameters

G	$56 \leq G \leq$	500	g/cm^2 sec
P	$40 \leq P \leq$	100	ata
D	$0.4 \leq D \leq$	1.2	cm.
L/D	L/D	not given	
X_o	$0 \leq X_o \leq$	0.4	
X_{in}	X_{in}	not given	
ϕ_o	ϕ_o	not given	

This range of validity is given by the authors.

Asymptotic Trend

$X_o \longrightarrow 0$ $\qquad$ $\phi_o = \dfrac{0{,}376}{D^{0{,}48}}\left(5{,}1\,H_{L_9}^{1{,}72}\,10^{-3} - G\right)$

$X_o \longrightarrow 1$ $\phi_o \rightarrow$ to values ≤ 0

$P \longrightarrow P_{crit}$ $\phi_o \rightarrow - \dfrac{0{,}376\,G}{D^{0,48}}$

$G \longrightarrow 0$ $\phi_o \rightarrow \dfrac{0{,}376}{D^{0,48}} \left[5{,}1.10^{-3} H_{L_e}^{1,72} (1-X_o)^m \right]$

$G \longrightarrow \infty$ $\phi_o \rightarrow -\infty$

The correlation does not depend on L.

Standard Form

$$\Phi_o = 315{,}4 \quad \frac{A' - 3{,}12\ 10^{-4}\ D\ G\ H_{lg}\ X_o}{C'}$$

$$A' = Y_0 \left(\frac{D}{2{,}54}\right)^{Y_1} \left(\frac{G}{135{,}6}\right)^{Y_2} \left(1+Y_3\ \frac{D}{2{,}54} + Y_4\ \frac{G}{135{,}6} + Y_5\ \frac{D\ G}{344}\right)$$

$$C' = Y_6 \left(\frac{D}{2{,}54}\right)^{Y_7} \left(\frac{G}{135{,}6}\right)^{Y_8} \left(1 + Y_9\ \frac{D}{2{,}54} + Y_{10}\ \frac{G}{135{,}6} + Y_{11}\ \frac{D\ G}{344}\right)$$

where the y_i ,constants dependent on the pressure,are given in the enclosed table III

Range of validity for the involved parameters

G	$1 \leq G \leq 1800$ g/cm^2 sec
P	defined only for P=40,70,110,140 ata
D	$0{,}09 \leq D \leq 2{,}5$ cm
L	$2{,}54 \leq L \leq 366$ cm

L/D	not given
X_o	$0 < X_o < 1$
X_{in}	$X_{in} < 0$
Φ_o	Φ_o not given

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

Asymptotic Trend

$X_o \rightarrow 0$ $\quad \Phi_o \longrightarrow 315{,}4 \dfrac{A'}{C'}$

$X_o \rightarrow 1$ $\quad \Phi_o \longrightarrow 315{,}4 \dfrac{A' - 3{,}12\,10^{-4}\, G\, D\, H_{l,s}}{C'}$

$P \rightarrow P_{cri}$ $\quad$ not defined

$G \rightarrow 0$ $\quad \Phi_o \longrightarrow 0$ for 140 ata

$\Phi_o \longrightarrow \infty$ for 40,70,110 ata

$G \rightarrow \infty$ $\quad \Phi_o \longrightarrow 0$ for 40,70,110 ata

$\Phi_o \longrightarrow \infty$ for 140 ata

Table III

OPTIMAL VALUES FOR Y_i

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

Standard Form

$$\phi_o = 3{,}63\, C_2 \, \frac{H_{eg}\left(\sigma\left(1+\frac{\rho_e}{\rho_g}\right)\right)^{3/4} \rho_e^{1/4}\,\rho_g^{1/2}}{G^{0{,}45}\, D^{0{,}7}\, \mu_e^{0{,}05}\left(1+\sqrt{\frac{\rho_e}{\rho_g}}\right)^{3/2}} \cdot \frac{\phi_{TPF}^{-1/4}}{\left[\frac{\rho_g}{\rho_e}+\frac{1+X_o(C_1-1)}{1-X_o}\right]} \quad \frac{\mathrm{watt}}{\mathrm{cm}^2}$$

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	$24 \leqslant G \leqslant 440$	g/cm^2-sec	
P	$42 \leqslant P \leqslant 175$	ata	
D	$0{,}122 \leqslant D \leqslant 1{,}22$	cm	Round ducts

D	$0.244 \leq D \leq 2.44$	cm.		rectangular and annular channels
L/D	$20 \leq L/D \leq 400$			
$L^{(+)}$	$15 \leq L \geq 275$	cm.		
X_o	$0 \leq X_o \geq 0.75$			
X_{in}	X_{in}	not given		
ϕ_o	ϕ_o	not given		

+ "Probably Range of Validity".

Asymptotic Trend

$X_o \to 0$	$\Phi_o \to 3{,}63\, C_2 \dfrac{H_{Lg}(\sigma(1+\rho_l/\rho_g))^{3/4}\rho_l^{5/4}\rho_g^{-1/2}}{G^{0,45}D^{0,7}\mu_l^{0,05}(1+\sqrt{\rho_l/\rho_g})^{3/2}\Phi_{TPF}^{1/4}}$
$X_o \to 1$	$\Phi_o \to 0$
$P \to P_{crit}$	$\Phi_o \to 0$
$G \to 0$	$\Phi_o \to \infty$
$G \to \infty$	$\Phi_o \to 0$

Standard Form

$$\phi_o = \frac{9}{32} H_{lg} \frac{G\,D}{L} \left\{ \frac{17}{9} \left[\left(0{,}825 + 2{,}36\, e^{-6{,}7D} \right) e^{-0{,}0111G} - 0{,}41\, e^{-0{,}0048L/D} - 1{,}12 \frac{\rho_g}{\rho_e} + 0{,}548 \right] - X_o \right\}$$

Range of validity for the involved parameters

G	$54 \leq G \leq 550$ g/cm^2 sec
P	$55 \leq P \leq 150$ ata
D	$0.254 \leq D \leq 1.37$ cm
L	$23 \leq L \leq 195$ cm
L/D	$21 \leq L/D \leq 660$
X_o	$0 < X_o < 0.9$
X_{in}	$0 > X_{in} > \frac{930 - H_s}{H_{lg}}$
ϕ_o	$30 < \phi_o < 550$ watt/cm^2.
P_{he}/P	$0{,}88 \leq \frac{P_{he}}{P} \leq 1$

Asymptotic Trend

$$X_{\bullet} \longrightarrow 0 \quad \phi_o \longrightarrow \frac{17}{32} H_{eg} \frac{GD}{L} \left\{ \left(0{,}825 + 2{,}36\, e^{-6{,}7D} \right) e^{-0{,}0111G} - 0{,}41\, e^{-0{,}0048L/D} - 1{,}12 \frac{\rho_g}{\rho_e} + 0{,}548 \right\}$$

$$X_{\bullet} \longrightarrow 1 \quad \phi_o \longrightarrow \frac{9}{32} H_{eg} \frac{GD}{L} \left\{ \frac{17}{9} \left[\left(0{,}825 + 2{,}36\, e^{-6{,}7D} \right) e^{-0{,}0111G} - 0{,}41\, e^{-0{,}0048L/D} - 1{,}12\, \rho_g / \rho_e + 0548 \right] \right.$$

$P \longrightarrow P_{crit}$ $\qquad$ $\phi_o \longrightarrow 0$

$G \longrightarrow 0$ $\qquad$ $\phi_o \longrightarrow 0$

$G \longrightarrow \infty$ $\qquad$ $\phi_o \longrightarrow \infty$

when L increases, $\phi_o \longrightarrow 0$.

S. Bertoletti - G. P. Gaspari - C. Lombardi - G. Peterlongo - M. Silvestri - F. A. Tacconi: CISE 3

Standard Form

$$\phi_o = \frac{0{,}794\ H_{Lg}\ P^{0,4}}{D^{0,4}\left(P_{cri} - P\right)^{0,4}}\left(a - X_o\right) \quad \text{Watt/cm}^2$$

where $a = \dfrac{P_{cri} - P}{P_{cri} \cdot (G/100)^{1/3}}$

Range of validity for the involved parameters

G	$100\left(1 - \frac{P}{P_{cri}}\right)^3 \leq G \leq 400$	g/cm^2 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_o	$X_o > 0$	
X_{in}	$X_{in} \leq 0.2$	
ϕ_o	ϕ_o not given	

This range of validity is given by the authors.

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

Asymptotic Trend

$$X_o \rightarrow 0 \qquad \phi_o \rightarrow \frac{0.794\ H_{Lg}\ P^{0,4}\ a}{D^{0,4}\left(P_{cri} - P\right)^{0,4}}$$

$X_o \longrightarrow 1$ $\phi_o \longrightarrow$ to negative values

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

$X_o = 0$

$G \longrightarrow 0$

$G \longrightarrow \infty$ the correlation is reduced to a straight line $X_o = 0$.

The correlation does not depend on L.

Standard Form

$$\phi_o = 0{,}115 \frac{D^{-3/5} G^{1/3} H_{eg}}{\beta(P)} \left\{ \frac{2{,}5\ \alpha(P)}{1+\frac{G}{135{,}6}} - X_o \right\} \ \text{watt/cm}^2$$

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

$$\alpha = \alpha(P) \cong -0.3126\ 10^{-8}\ P^4 + 0.133\ 10^{-2} P + 0.7123$$

$\beta = \beta(P)$ is given as ratio with $\alpha(P)$

$$\alpha(P)/\beta(P) \cong 0.34 + 9.4/(P - 7.3)$$

Range of validity for the involved parameters

G	$68 \leq G \leq 410$	g/cm^2 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_o	$X_o > 0$	
X_{in}	$-0.37 < X_{in} < 0$	
ϕ_o	ϕ_o not given	

Asymptotic Trend

$$X_o \longrightarrow 0 \qquad \phi_o \longrightarrow 0{,}115 \frac{D^{-3/5} G^{1/3} H_{eg}}{\beta(P)} \quad \frac{2{,}5\ \alpha(P)}{1+\frac{G}{135{,}6}}$$

$X_o \longrightarrow 1$ $\qquad \phi_o \longrightarrow 0{,}115 \dfrac{D^{-3/5}\, G^{1/3}\, H_{eq}}{\beta(P)} \left\{ \dfrac{2{,}5\ \alpha(P)}{1 + \dfrac{G}{135{,}6}} - 1 \right\}$

$P \longrightarrow P_{crit}$ for this value α (P) and β(P) are not defined

$G \longrightarrow \infty$ ϕ_o is reduced to the point $\phi_o = 0$; $X_o = 0$

$G \longrightarrow 0$ $\phi_o \longrightarrow 0$

The correlation does not depend on L.

V. N. Smolin - V. K. Polyakov - V. I. Esikov

Standard Form

$$\phi_o = 2{,}36 \cdot 10^{5} \frac{(\Theta + 273)K}{H_{lg}} \frac{(\rho_l - \rho_g)^{0{,}75} \rho_l^2}{\rho_g^3} \left(\frac{\sigma}{g}\right)^{0{,}25} \left(\frac{\mu_l}{G}\right)^{0{,}45} \frac{P_r^2}{D^{0{,}95}} \left[\frac{1 + \left(\frac{\mu_l}{\mu_g} - 1\right) X_o}{1 + \left(\frac{\rho_l}{\rho_g} - 1\right) X_o}\right]^3 \ \text{watt/cm}^2$$

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

Range of validity for the involved parameters:

G	$100 \leq G \leq 800$	g/cm^2 sec		
P	$98 \leq P \leq 196$	ata	when	$X_o > 0.05$
P	$78 \leq P < 98$	ata	when	$X_o > 0.10$
P	$49 \leq P < 78$	ata	when	$X_o > 0.15$
D	$0.5 \leq D \leq 1.6$	cm.		
L	$L > 260$	cm.		
L/D	L/D	not given		

X_o

$$X_o > \frac{2{,}11 \cdot 10^{-5} \frac{G D^{0{,}5}}{\mu_l} \cdot \left(\frac{\sigma}{(\rho_l - \rho_g) g}\right)^{0{,}25}}{\left(P/P_{crit}\right)^{-2{,}28} \left(\mu_l/\mu_g - 1\right) + \left(\rho_l/\rho_g - 1\right) 2{,}11 \cdot 10^{-5} \frac{G D^{0{,}5}}{\mu_l} \left(\frac{\sigma}{(\rho_l - \rho_g) g}\right)^{0{,}25}}$$

$X_{in}^{(+)}$	$X_{in} < 0$	
ϕ_o	ϕ_o	not given

(+) - This restriction is not given explicitly.

The range of validity is given by the authors

Asymptotic Trend

$X_o \longrightarrow 0$ $\qquad \phi_o \longrightarrow 2{,}36\cdot 10^5 \left(\frac{\theta + 273}{H_{\ell g}\,\rho_g^3}\right) K \left(\rho_\ell - \rho_g\right)^{0{,}75} \rho_\ell^2 \left(\frac{\sigma}{g}\right)^{0{,}25} \left(\frac{\mu_\ell}{G}\right)^{0{,}45} \frac{P_r^2}{D^{0{,}95}}$

$X_o \longrightarrow 1$ $\qquad \phi_o \longrightarrow 2{,}36\cdot 10^5 \frac{(\theta + 273)K}{H_{\ell g}\,\rho_g^3} \left(\rho_\ell - \rho_g\right)^{0{,}75} \rho_\ell^2 \left(\frac{\sigma}{g}\right)^{0{,}25} \left(\frac{\mu_\ell}{G}\right)^{0{,}45} \frac{P_r^2}{D^{0{,}95}} \left[\frac{\mu_\ell/\mu_g}{\rho_\ell/\rho_g}\right.$

$P \longrightarrow P_{crit}$ $\qquad \phi_o \longrightarrow 0$

$G \longrightarrow 0$ $\qquad \phi_o \longrightarrow \infty$

$G \longrightarrow \infty$ $\qquad \phi_o \longrightarrow 0$

The correlation does not depend on L

K. M. Becker - P. Persson

1st correlation

Standard Form

We determine first of all $\phi_o^* = \dfrac{b \quad H_{\ell g}}{V_{\ell g} \, G^{1/2} \quad B}$ Watt/cm^2

where $$B = \frac{- \lg\left(1-X_o^*\right) + \lg\left(0{,}98 - \dfrac{\varepsilon\, v\, B^{1/2}}{X_o^{*1/4}(B+1)}\right) - \lg\left(1 - \dfrac{\varepsilon\left(X_o^* + v\right) B^{1/2}}{\left(1-X_o^*\right) X_o^{*1/4}\left(B+1\right)}\right)}{\lg \dfrac{X_o^* + v}{v}}$$

Successively we find ϕ_o and X_o by means of the two expressions:

$$\phi_o = K_d \; \phi_o^* \qquad \text{Watt/cm}^2$$

$$X_o = X_o^* + \frac{4\left(K_d - 1\right) L}{G \;\; H_{\ell g} \;\; D} \, \phi_o^*$$

ε 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 diagrams of the Report AE-178.

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

$$\varepsilon = \varepsilon\left(P\right) \approx -0{,}385 \cdot 10^{-6} P^3 + 2{,}1867 \; 10^{-4} P^2 - 2{,}1182 \; 10^{-2} P + 0{,}5913$$

$$b = b(P) \approx 1{,}0677/P - 0{,}6688 \cdot 10^{-6} P^3 + 0{,}199 \cdot 10^{-3} P^2 - 0{,}02184\,P + 1{,}0876$$

$$K_d = K_d(D) \approx \begin{cases} 0{,}9 + 0{,}29\, e^{-4{,}25(D-0{,}5)^2} & D < 1{,}2 \\ 1{,}019 - 0{,}048\, D & D \geqslant 1{,}2 \end{cases}$$

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_e	$0 \leq X_e < 1$	

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

ϕ_o $35 < \phi_o < 686$ watt/cm.^{2}

This range of validity is given by the authors.

Asymptotic Trend

$X_e \longrightarrow 0.02$		ϕ_o has an asymptotte	
$X_e \longrightarrow 1$		$\phi_o \longrightarrow 0$	
$P \longrightarrow P_{crit}$	for this value ϕ_o is not defined		
$G \longrightarrow 0$		$\phi_o \longrightarrow \infty$	
$G \longrightarrow \infty$		$\phi_o \longrightarrow 0$	

The correlation does not depend on L.

2nd correlation

Standard Form

We determine first of all

$$\phi_o^* = \frac{3{,}16 \cdot 10^3}{G^{1/2}\left(a_1 + \frac{X_o^*}{a_o}\right)} \qquad \mathrm{Watt/cm^2}$$

where a_o and a_1 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:

$$a_o = a_o(P) \approx -118.505/P^2 + 0.113281 \cdot 10^{-5} P^3 - 0.196885 \cdot 10^{-3} P^2 + 1.13773$$

$$a_1 = a_1(P) \approx 0.196257 \; 10^{-6} \; P^3 - 0.124829 \; 10^{-2} P + 0.40475$$

Successively we find ϕ_o and X_o by means of:

$$\phi_o = K_d \, \phi_o^* \qquad \mathrm{Watt/cm^2}$$

$$X_o = X_o^* + \frac{4(K_d - 1)L}{G \cdot H_{eg} \cdot D} \phi_o^*$$

k_d is a constant dependent on the diameter, given by the diagram of the Report RTL-798 (fig. 3). By means of a linear regression program we have obtained from such a diagram the following approximated expression:

$$K_d = K_d(D) \approx \begin{cases} 0{,}9 + 0{,}29\, e^{-4{,}25(D-0{,}5)^2} & D < 1{,}2 \\ 1{,}019 - 0{,}048\, D & D \geq 1{,}2 \end{cases}$$

Range of validity for the involved parameters:

G	12	$\leq$	G	$\leq$	700	$g/cm.^2$	sec
P	20	$\leq$	P	$\leq$	91	ata	
D	0.4	$\leq$	D	$\leq$	3.75	cm.	
L	40	$\leq$	L	$\leq$	375	cm.	
L/D	40	$\leq$	L/D	$\leq$	890		
X_e	-0.05	$<$	X_e	$\leq$	0.5		

X_{in} corresponding to $30 < \Delta T_{sub} < 240$ °C

ϕ_o $50 \leq \phi_o \leq 700$ watt/cm^2.

This range of validity is given by the author.

Asymptotic Trend

$X_0 \longrightarrow 0 \qquad \phi_0 \longrightarrow \dfrac{3,6 \cdot 10^3}{a_1 \quad G^{1/2}}$

$X_0 \longrightarrow 1 \qquad \phi_0 \longrightarrow \dfrac{3,6 \cdot 10^3}{G^{1/2}\left(a_1 + \dfrac{1}{a_0}\right)}$

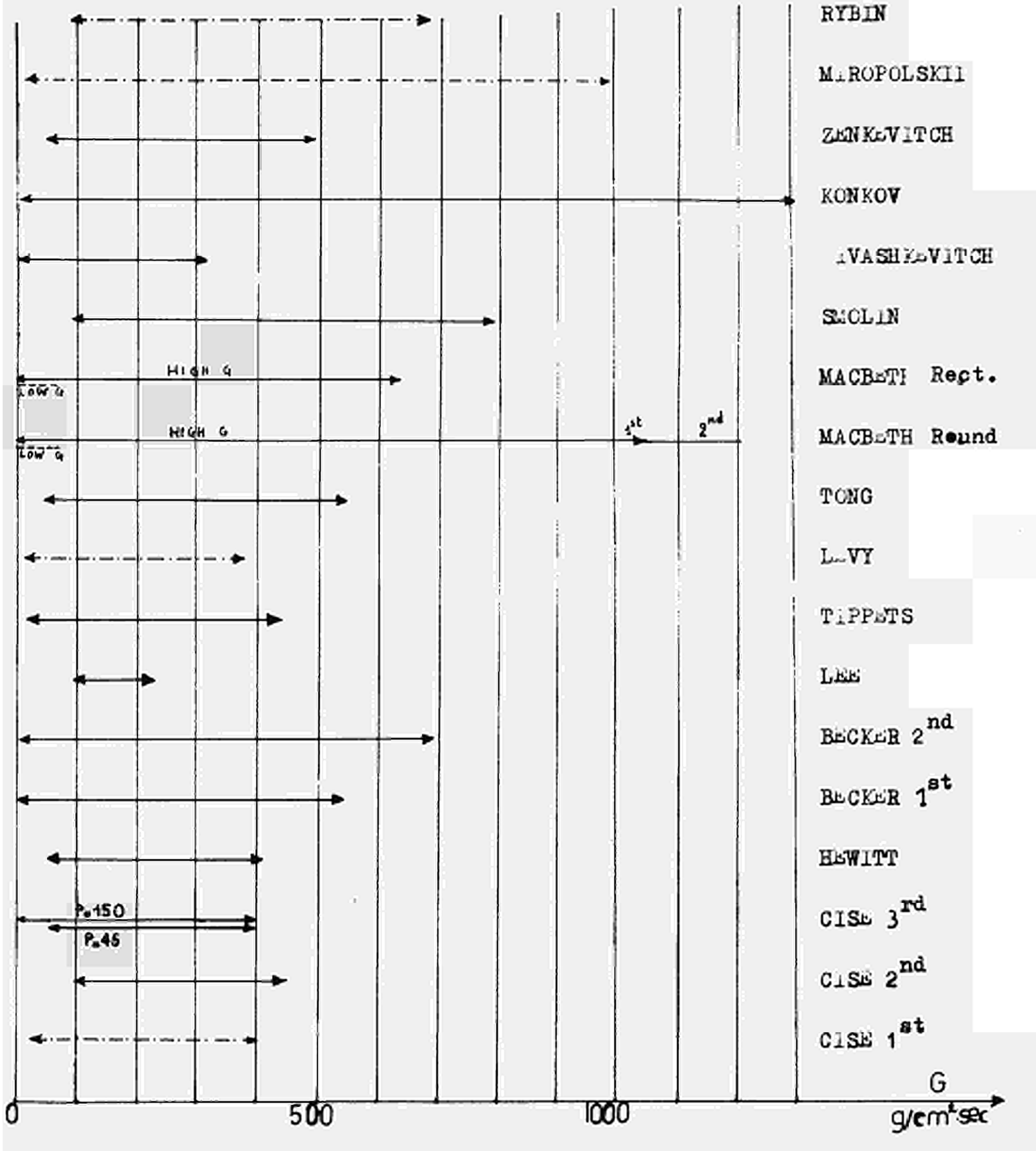
For $P \longrightarrow P_{crit}$ a_0 and a_1 are not defined

$G \longrightarrow 0 \qquad \phi \longrightarrow \infty$

$G \longrightarrow W \qquad \phi \longrightarrow 0$

The correlation does not depend on L.

RANGE OF VALIDITY FOR G



——— given by the authors

— · — · — Probably Range of Validity

Fig. 1

RANGE OF VALIDITY FOR PRESSURE

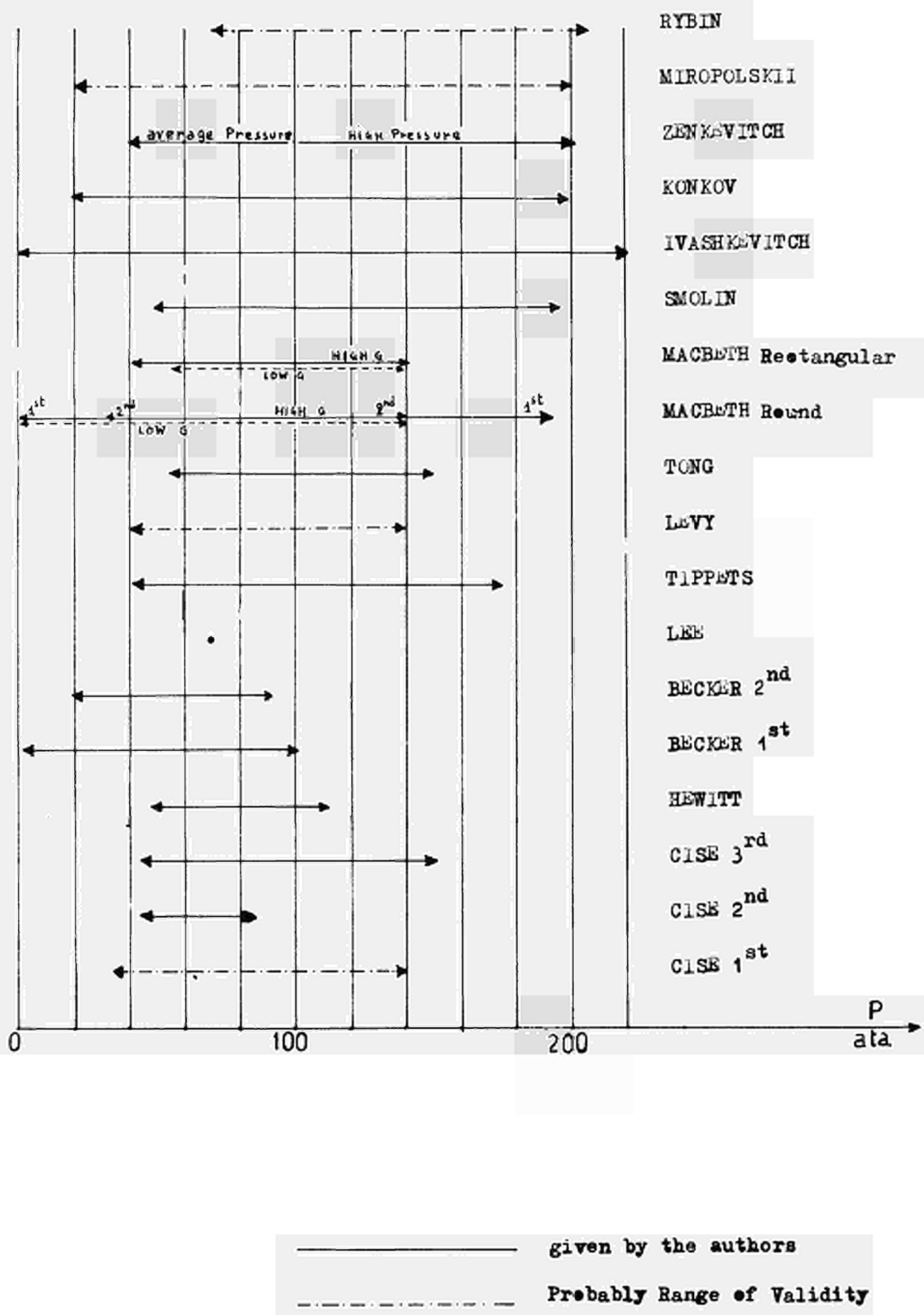


Fig.2

RANGE OF VALIDITY FOR D

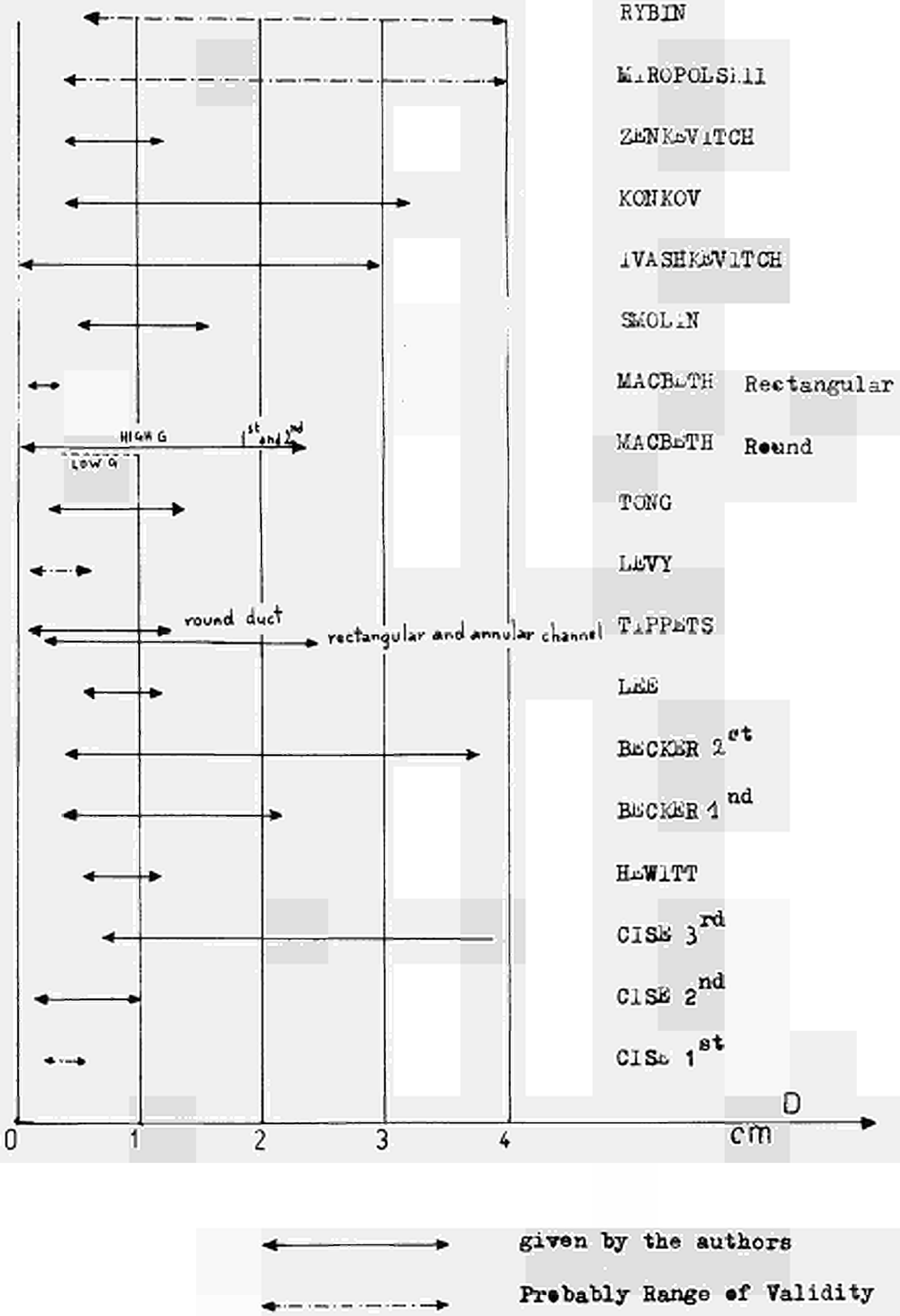
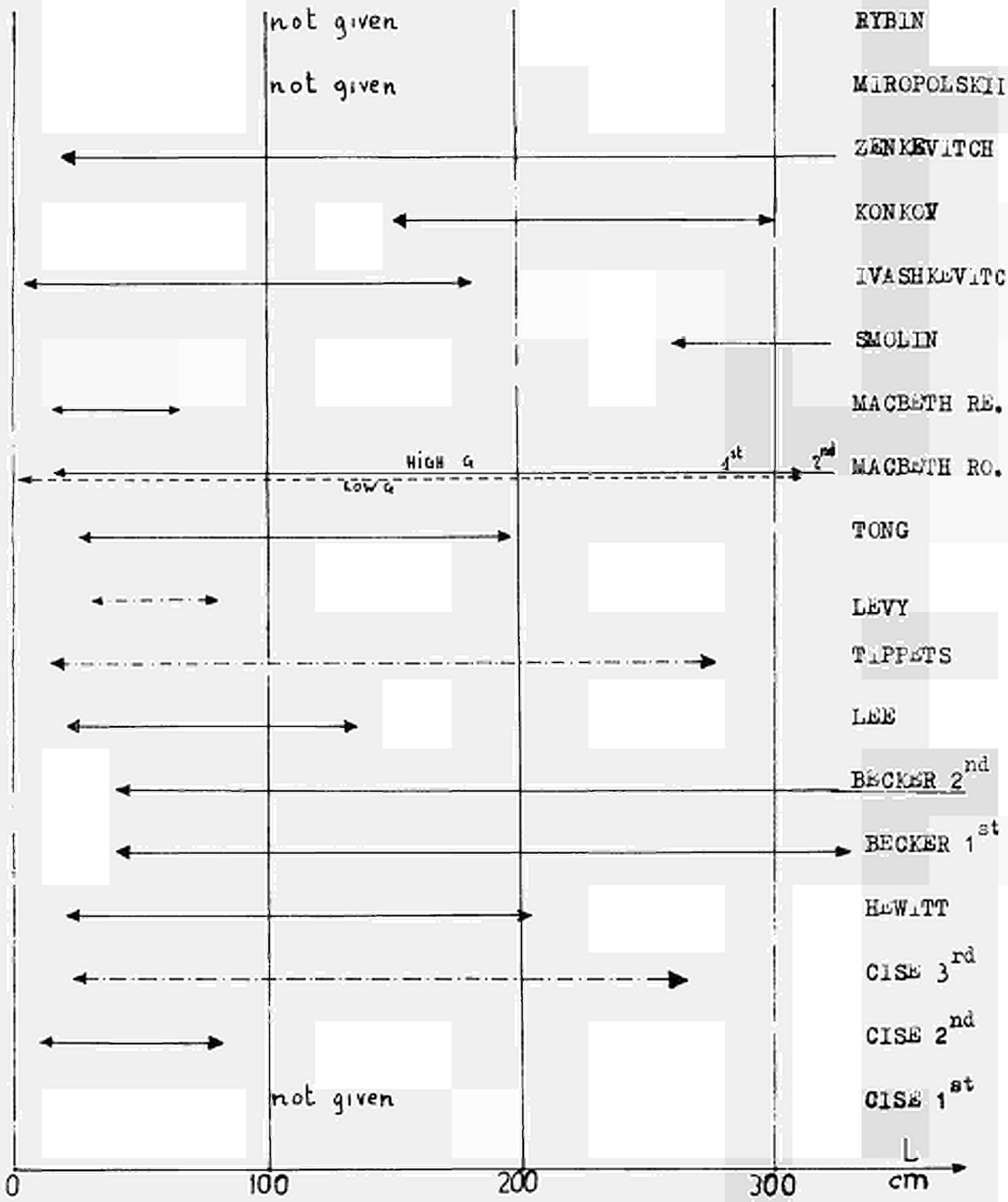


Fig. 3

RANGE OF VALIDITY FOR L



given by the authors

it is not given a limit on the right

Probably Range of Validity

Fig.4

RANGE OF VALIDITY FOR L/D

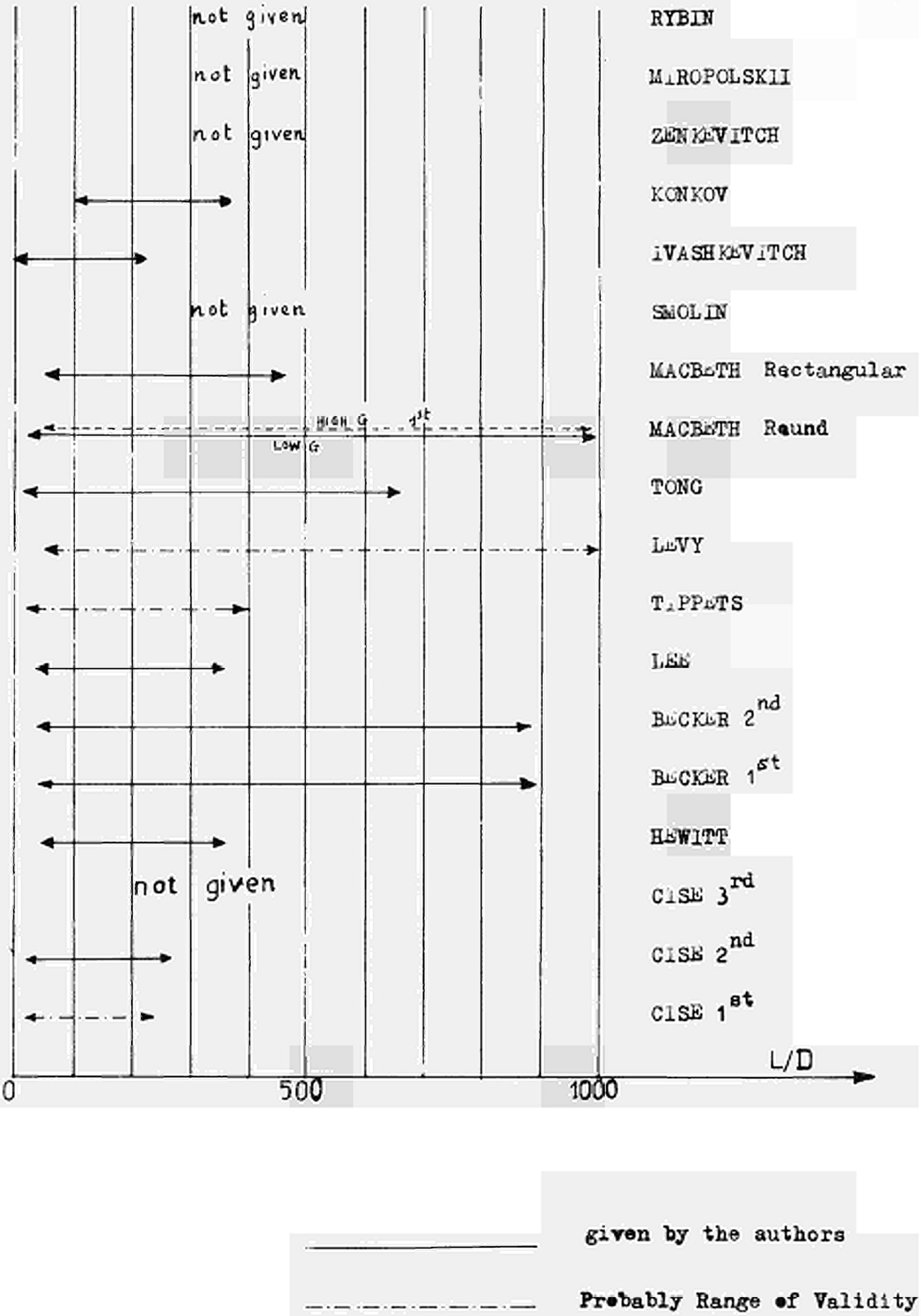


Fig. 5

RANGE OF VALIDITY FOR X_o

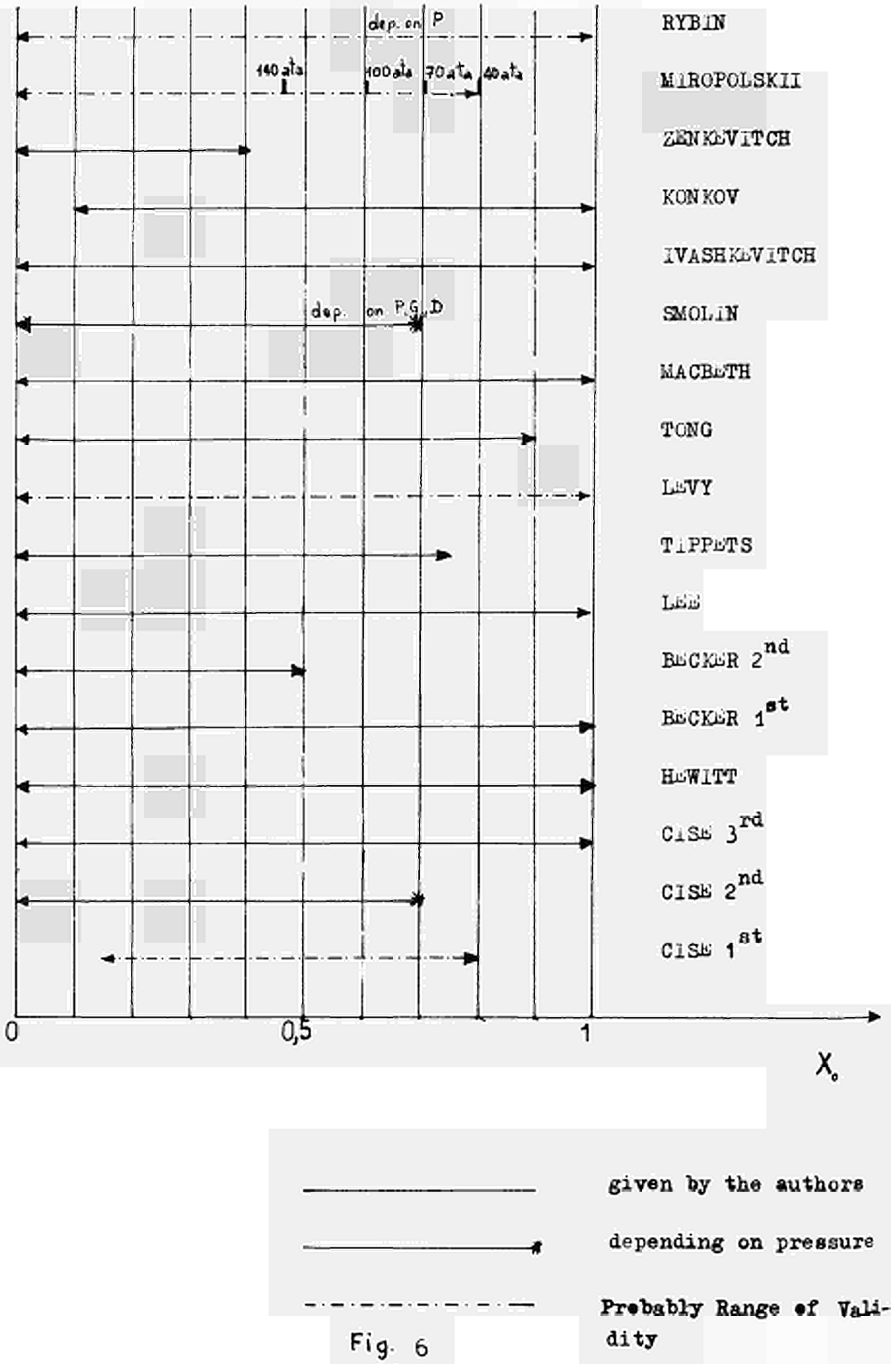


Fig. 6

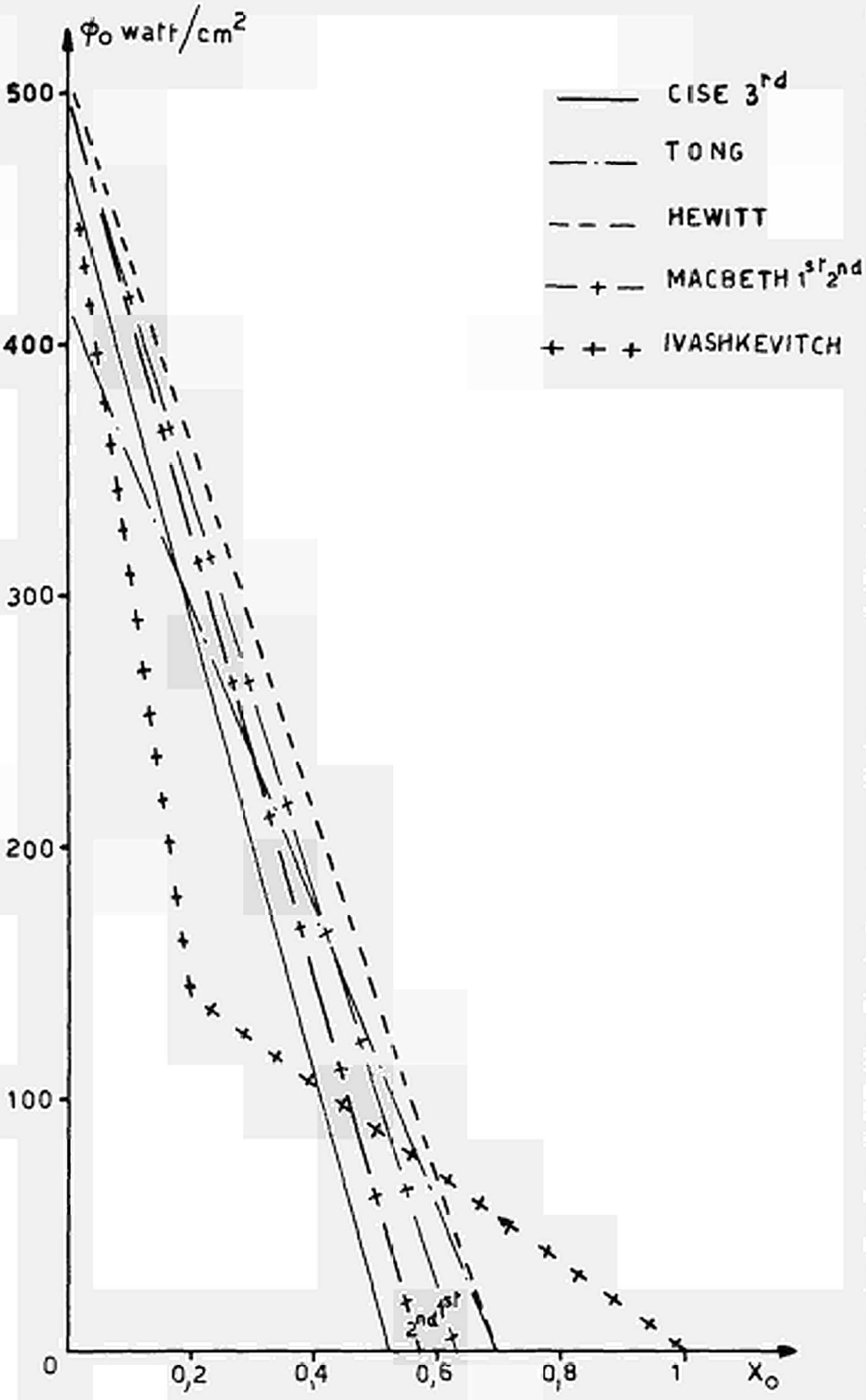
	G	P	D	L	L/D	X_o	X_{in}	Φ_o
CISE I	27–420	35–140	0.25–0.5	–	21–365	0.15–0.80	<0	63–630
CISE II	100–450	45–85	0.3 –1	10–80	20–266	$< X_{crit}$	-0.05–0.7	10–500
CISE III	G(P)	45–150	>0.7	20.3–267	–	>0	<0.2	–
Hewitt	58–410	49–112	0.55–1.13	21–205	39–360	>0	-0.37–0	–
Becker I	12–545	2.7–101	0.4–2.5	40–390	40–890	0–1	–	35–686
Becker II	12–700	20–91	0.4–3.75	40–375	40–890	-0.05–0.5	–	50–700
Lee-Ober	102–225	70	0.56–1.15	22–135	39–360	>0	-0.23–0	–
Tippets	24–440	42–175	0.122–1.22	15–275	20–400	0 – 0.75	–	–

	G	P	D	L	L/D	X_o	X_{in}	ϕ_o
Levy	20–380	42–140	0.13–0.46	30–81	> 60	> 0	< 0	–
Tong	54–550	55–150	0.254–1.37	23–195	21–660	0–0.9	–	30–550
Macbeth Ro. Low G	1.36–84	1.06–141	0.304–0.99	15.2–310	> 50	0–1	-1.31–0	–
Macbeth Re. Low G	2.21–75	56–141	0.13 –0.256	15.2 – 64.8	60–460	0–1	-1.25–0	–
Macbeth II	1–1800		0.09–2.5	2.54–366	–	0–1	< 0	–
Smolin	100–800	49–196	0.5–1.6	> 260	–	X_o (P)	< 0	–
Ivashkevitch	15–325	1–220	0.02–3	3.5–180	1–220	0–1.0	-0.8–0	–

	G	P	D	L	L/D	X_o	X_{in}	ϕ_o
Macbeth Ro. High G	1.356–1060	1.06–193	0.101–2.37	2.54–310	> 50	0–1	-2.5–0	–
Macbeth Re. High G	13.56–648	42–141	0.13 –0.256	15.2–68.4	60–460	0–1	–1.435–0	–
Konkov	10–1320	20–200	0.4 –3.22	150 –300	93–375	> 0,1	< 0	10–390
Zenkevitch	56–110–500	40–100–200	0.4 –1.2	20	–	0–0.4	–	–
Miropolskii	20–1000	20–200	> 0.4	–	–	< 0.8 dep. on P	–	–
Ribin	80–700	70–206	> 0,6	–	–	> 0	< 0	65 –450

PART 3

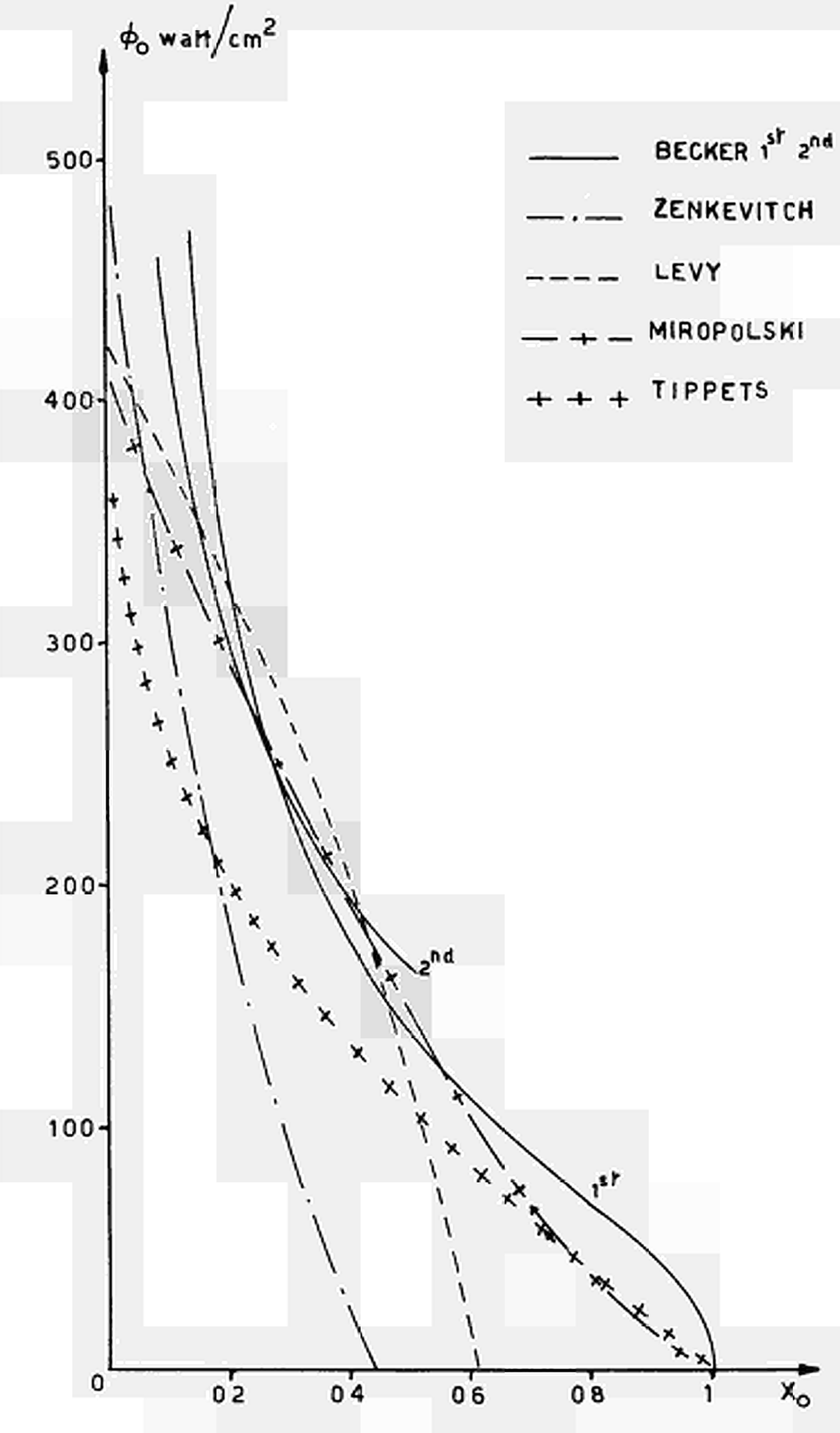
GRAPHYCAL COMPARISON



P = 72 ata   G = 219 gr/cm^2 sec

D = 0,918 cm   L = 139,9 cm

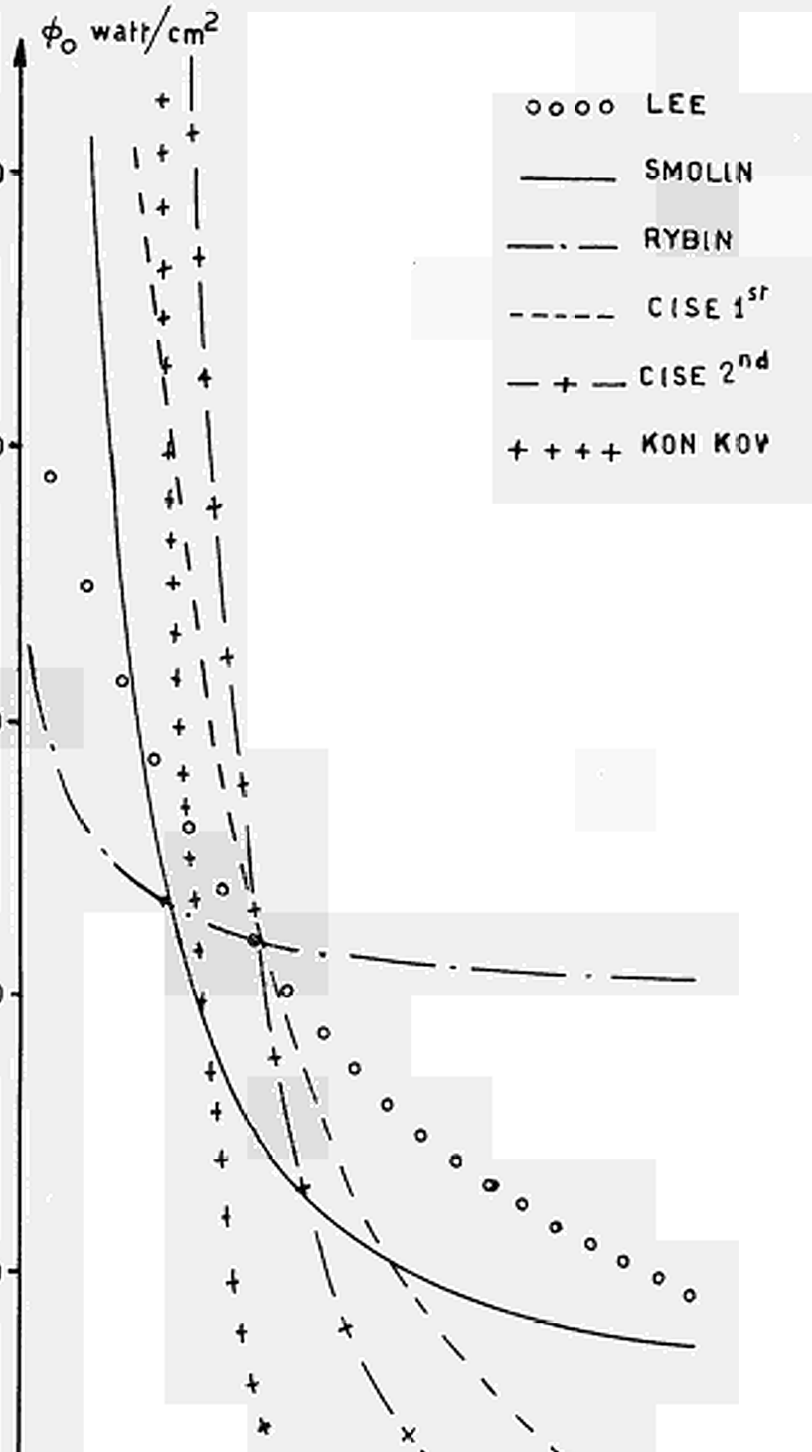
Fig. 7



P = 72 ata G = 219 gr/cm² sec

D = 0,918 cm L = 139,9 cm

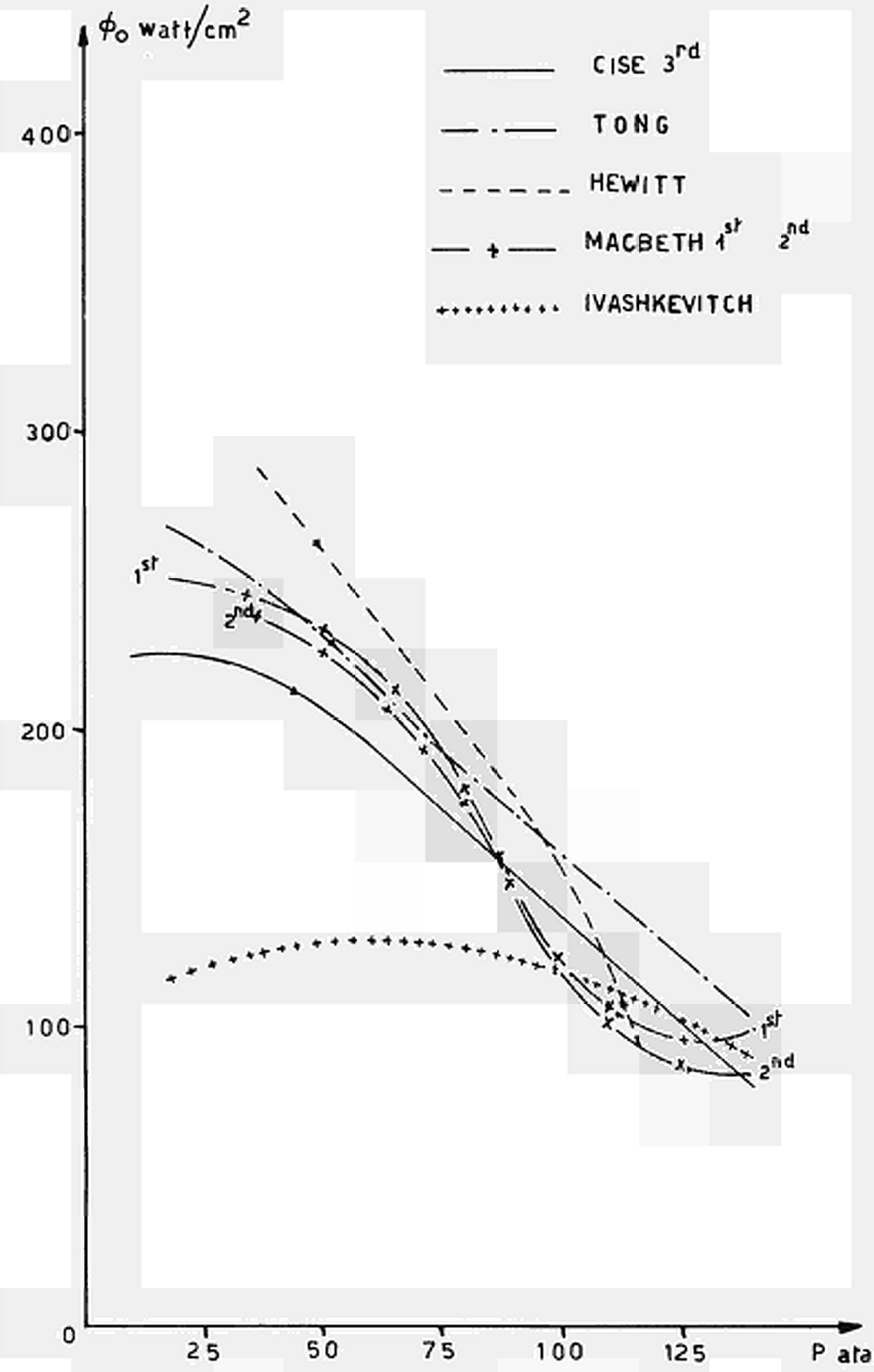
Fig. 8



P = 72 ata G = 219 gr/cm^2 sec

D = 0,918 cm L = 139,9 cm

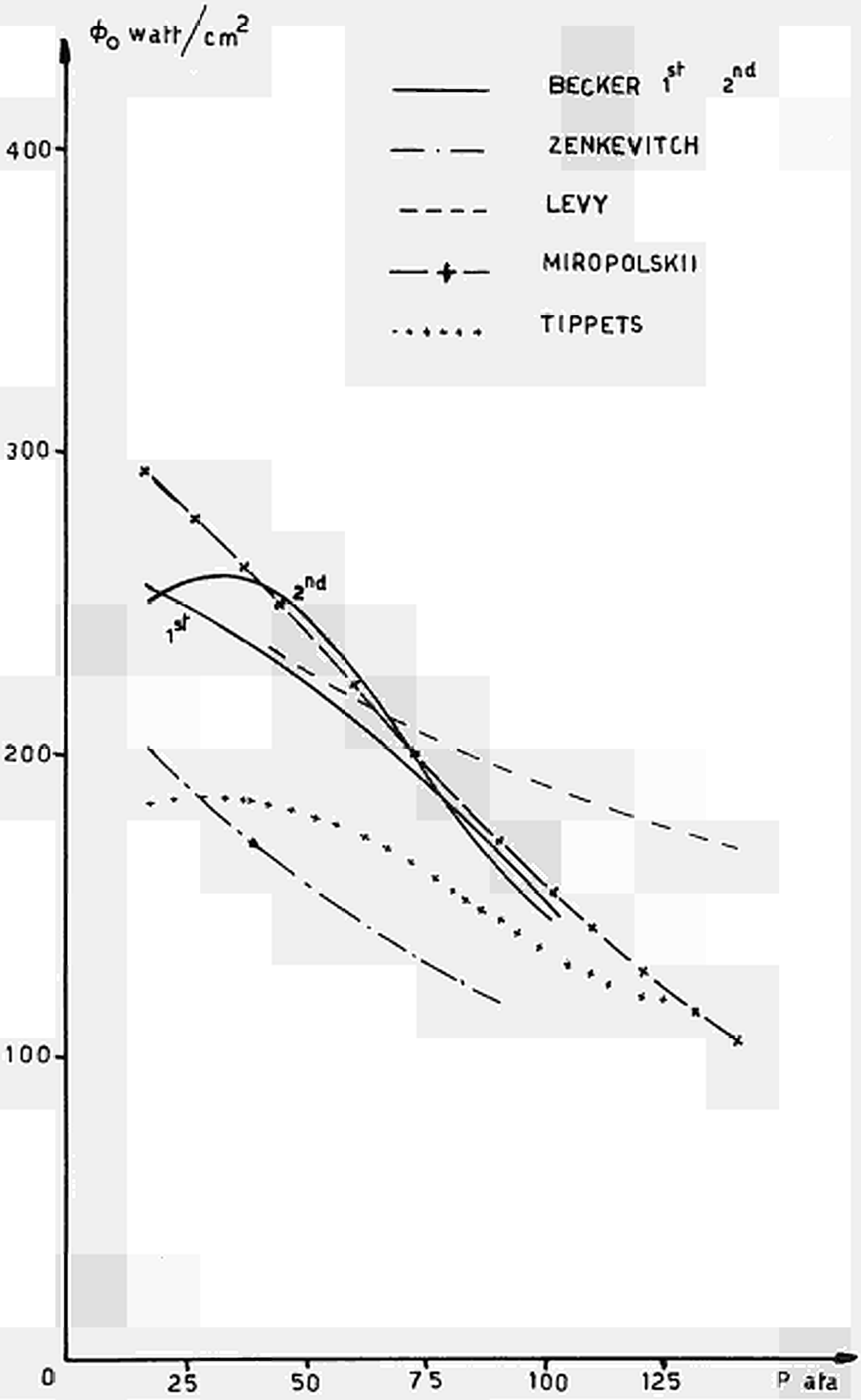
Fig. 9



$X_{in} = 0$ $G = 219$ gr/cm^2 sec

$D = 0{,}918$ cm $L = 139{,}9$ cm

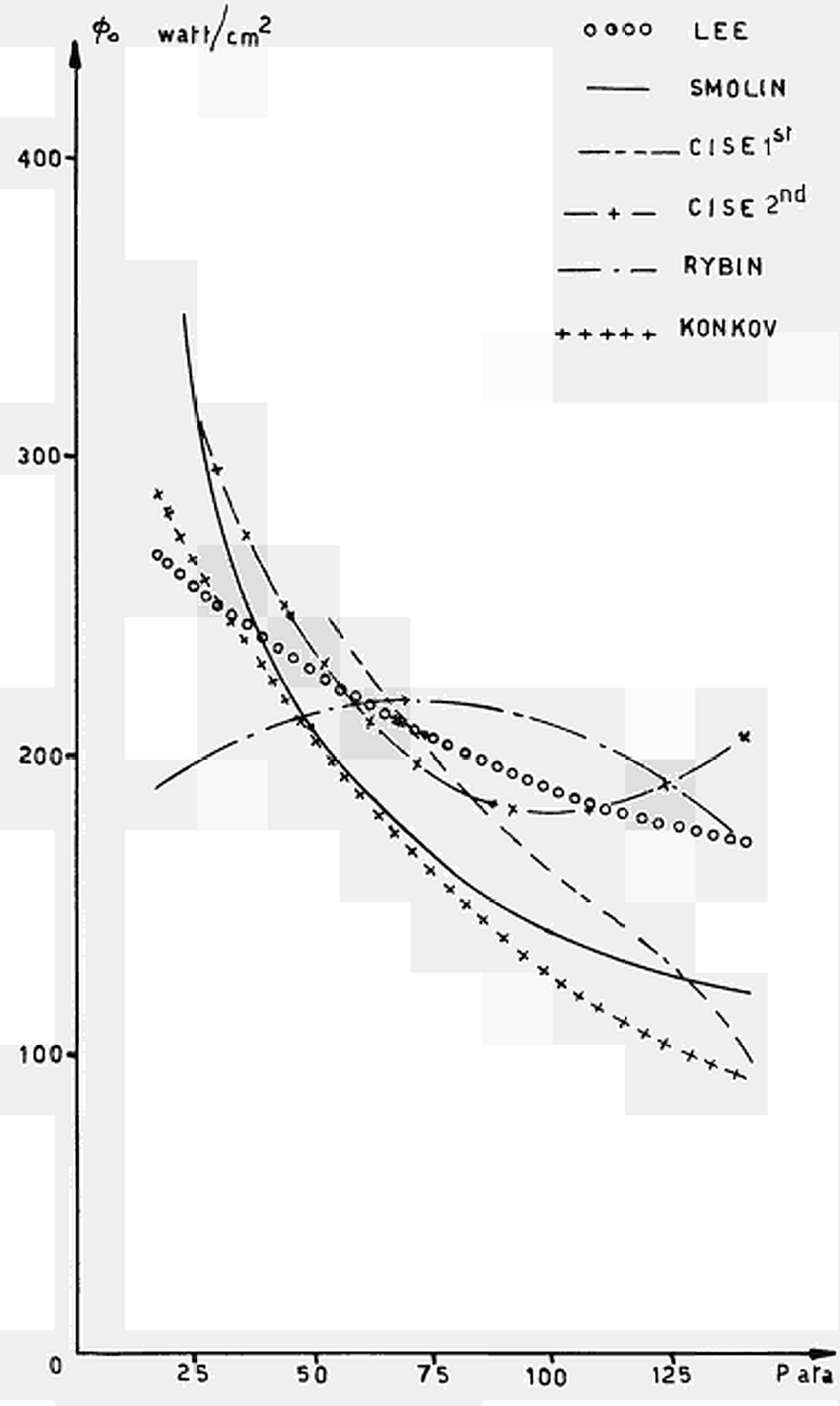
Fig.10



$X_{in} = 0$ G = 219 gr/cm^2 sec

D = 0,918 L = 139,9

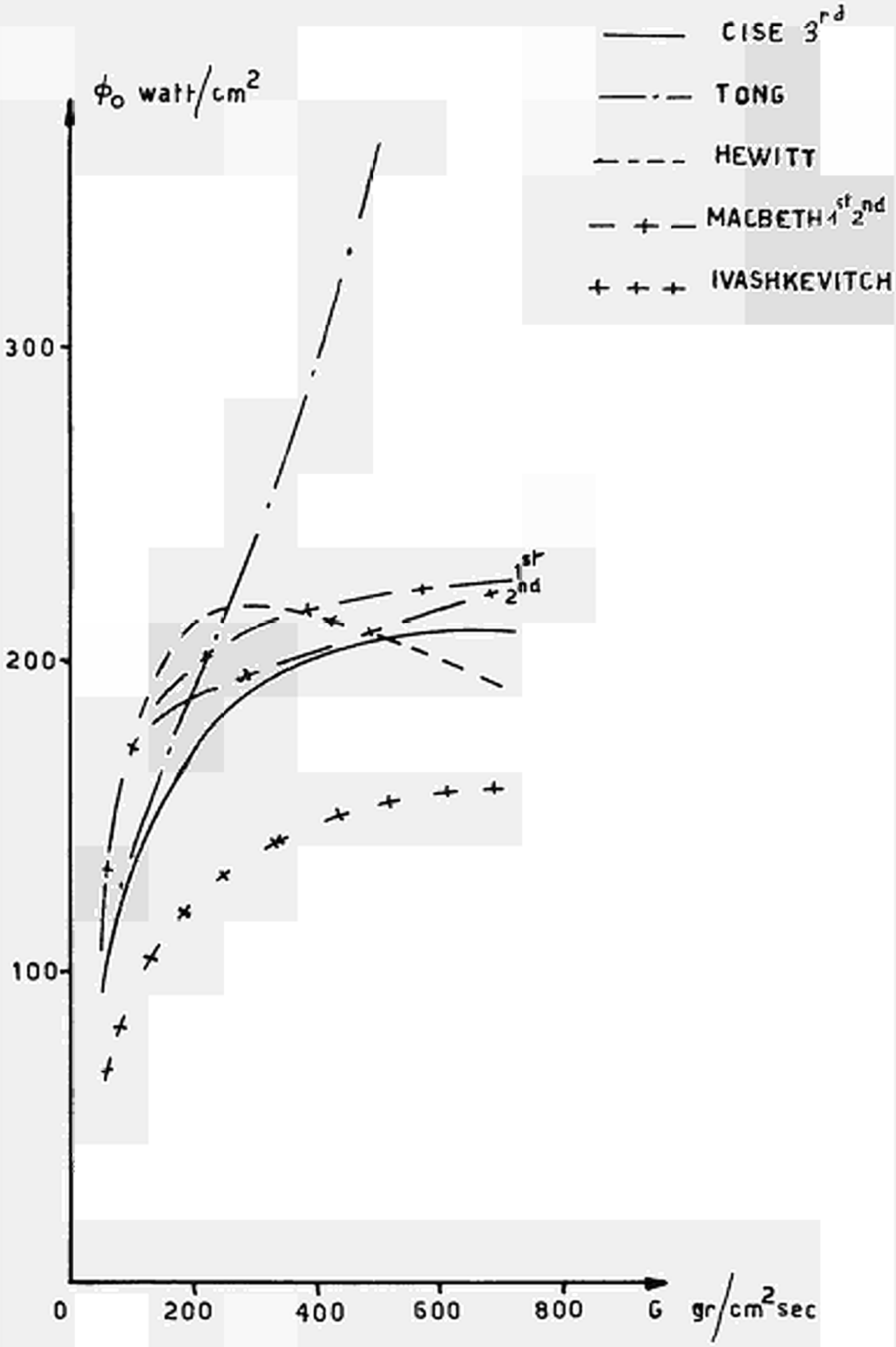
Fig.11



$X_{in} = 0$ $G = 219$ gr/cm^2 sec

$D = 0{,}918$ cm $L = 139{,}9$ cm

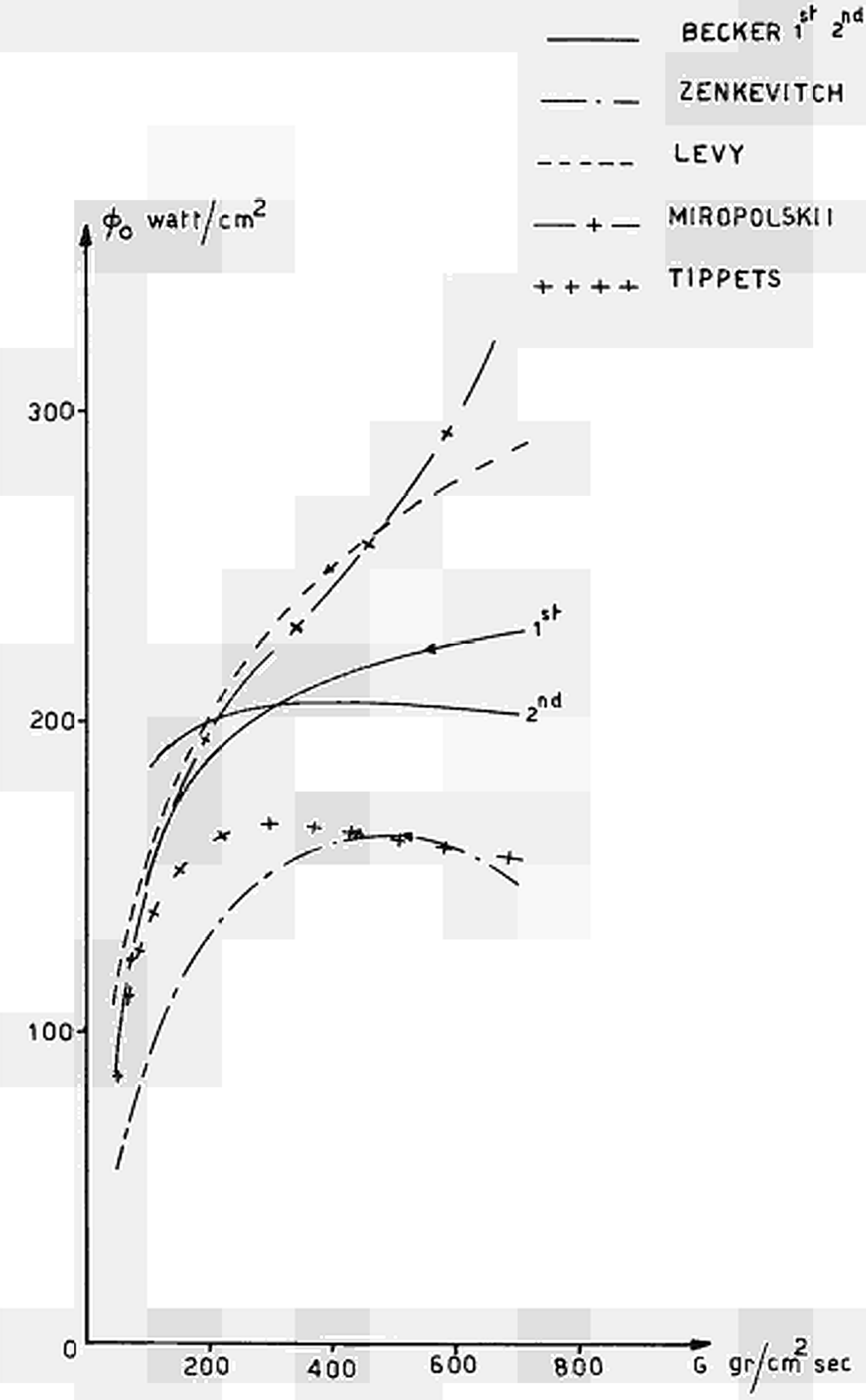
Fig. 12



P= 72 ata $X_{in} = 0$

D = 0,918 cm L = 139,9 cm

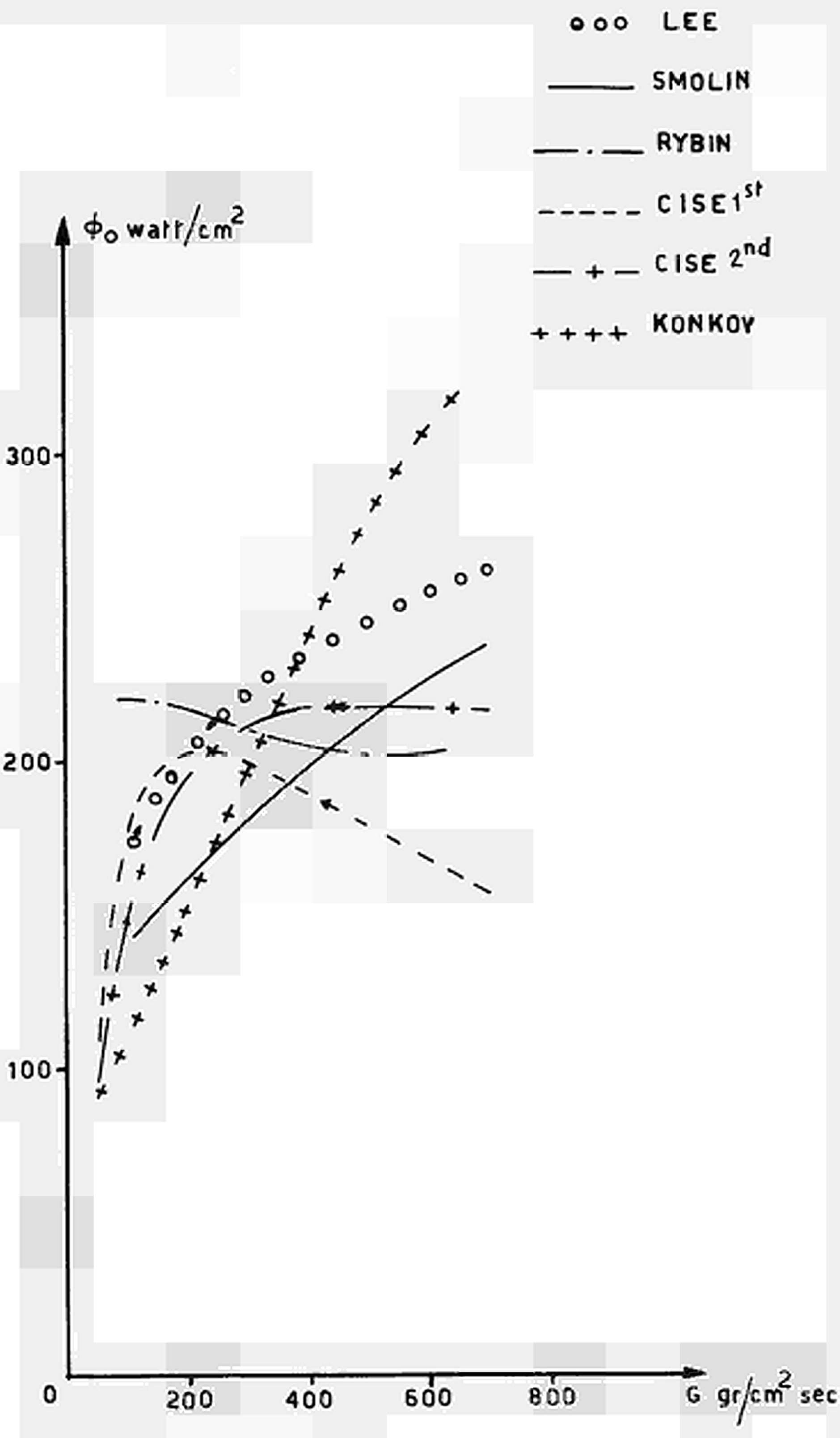
Fig. 13



P = 72 ata $X_{in} = 0$

D = 0,918 cm L = 139,9 cm

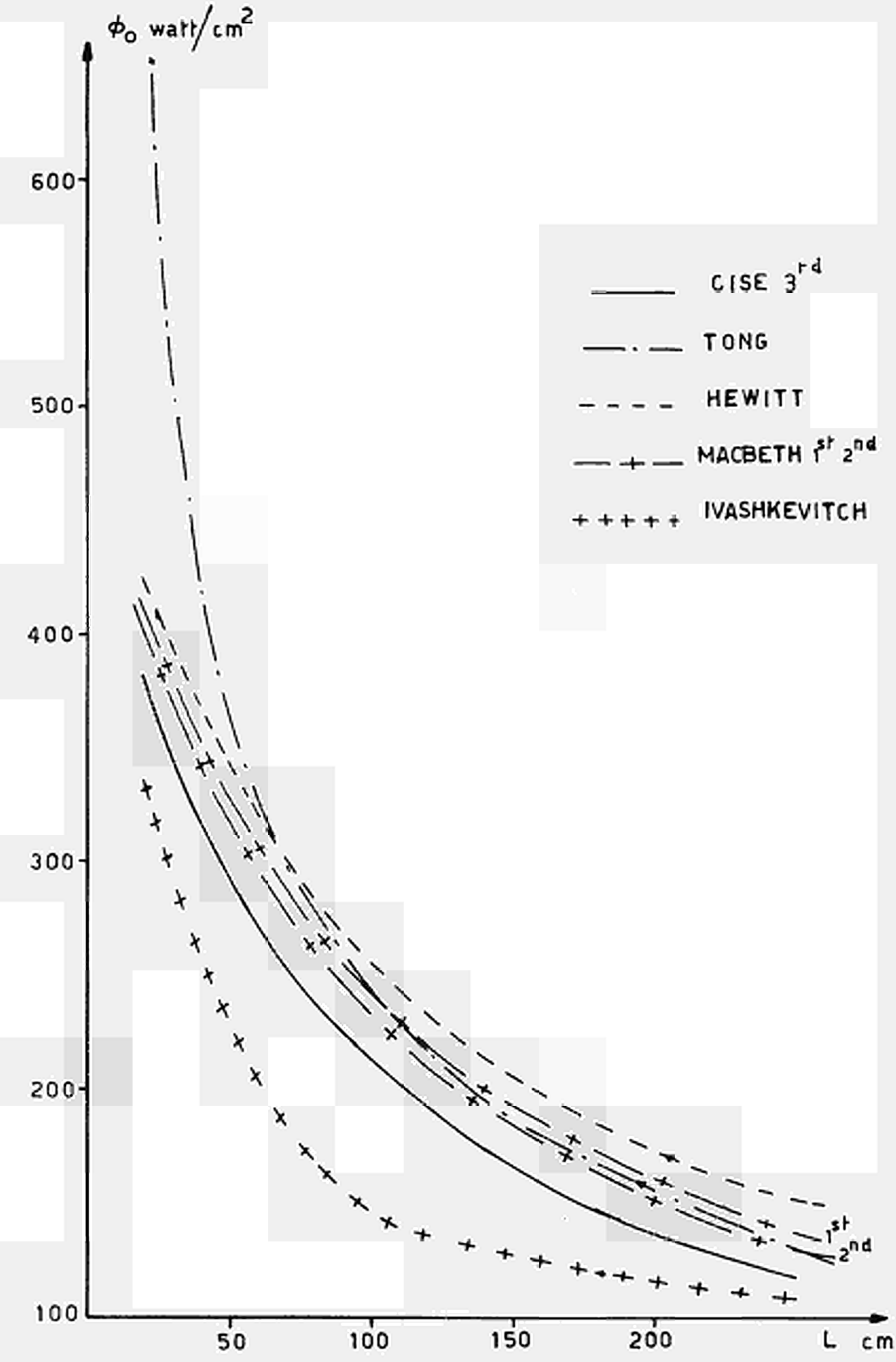
Fig. 14



P = 72 ata $X_{in} = 0$

D = 0,918 cm   L = 139,9 cm

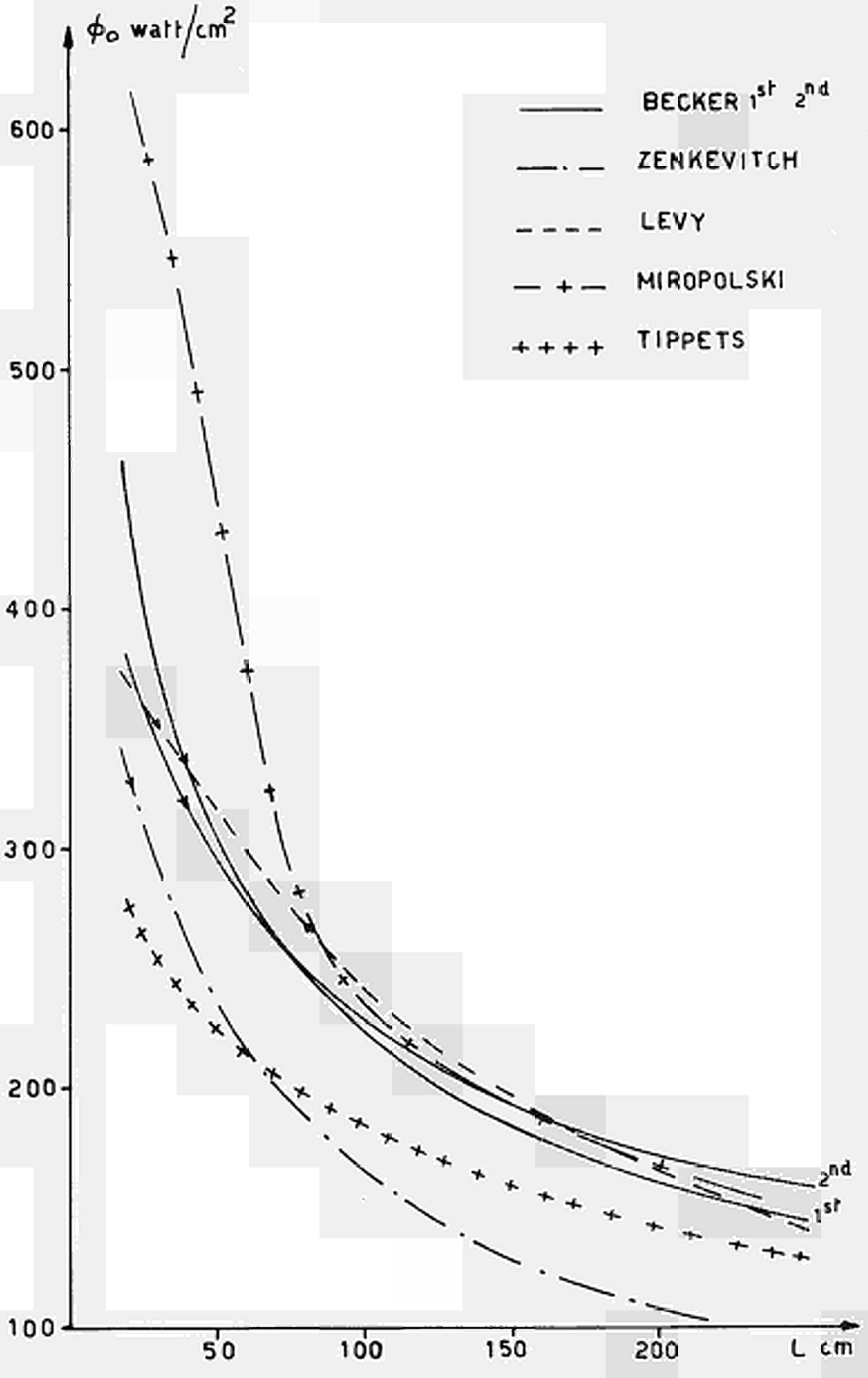
Fig. 15



P = 72 ata X_{in} = 0

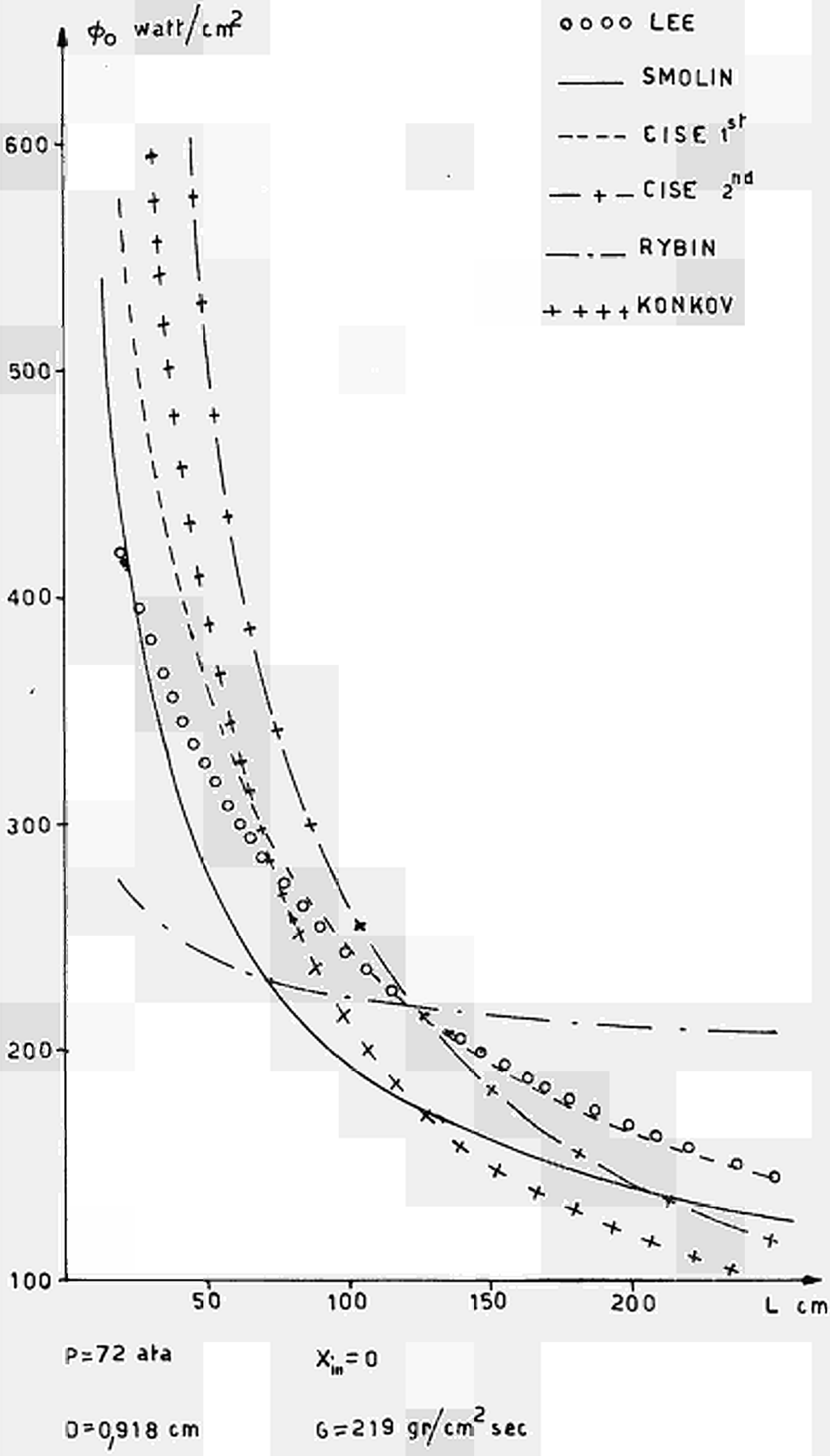
D = 0,918 cm G = 219 gr/cm^2 sec

Fig. 16



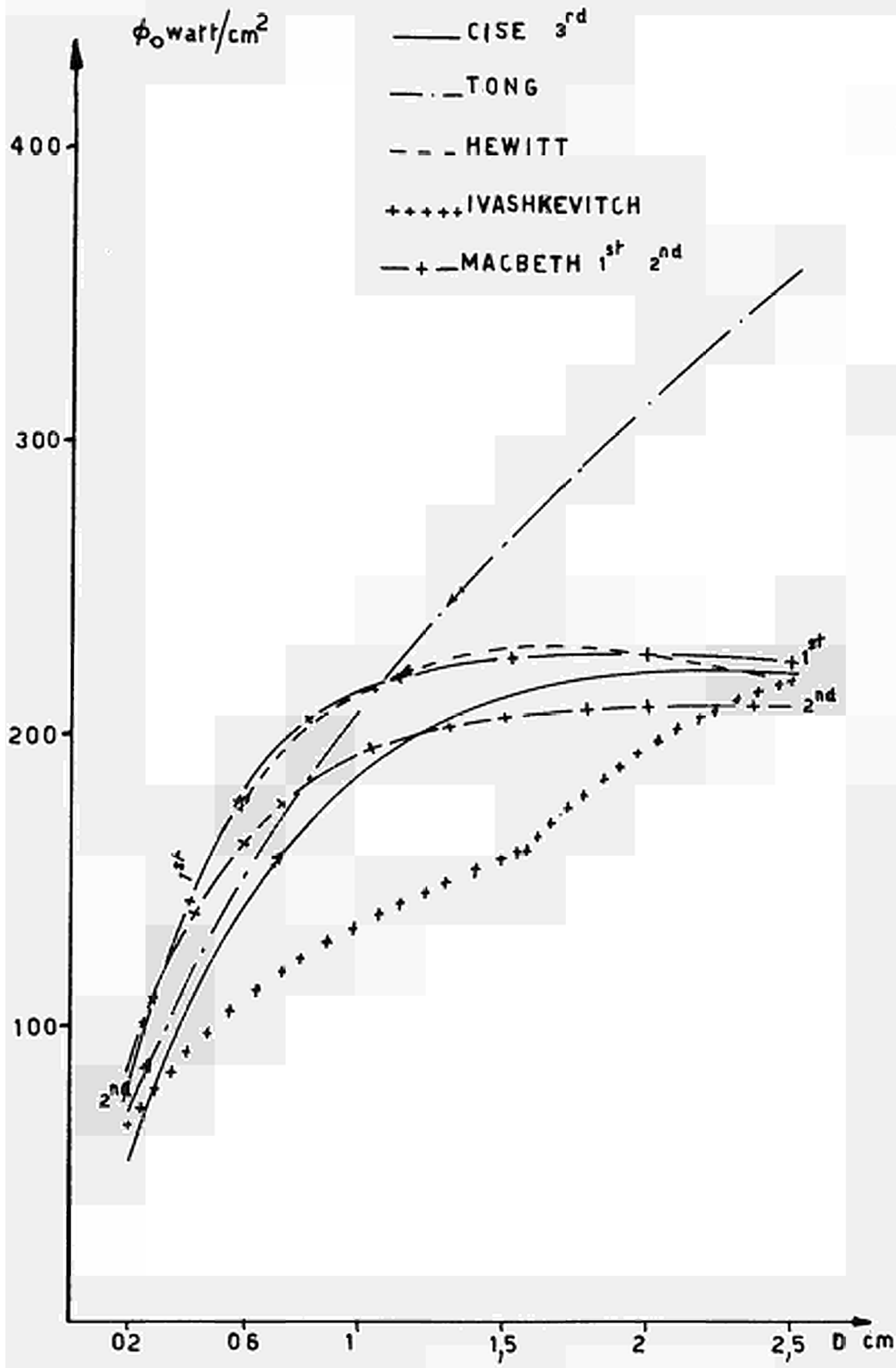
P = 72 ata
$X_{in} = 0$
D = 0,918 cm
G = 219 gr/cm^2 sec

Fig. 17



ϕ_0 watt/cm^2
oooo LEE
SMOLIN
CISE 1st
CISE 2nd
RYBIN
++++ KONKOV
600
500
400
300
200
100
50
100
150
200
L cm
P=72 ata
$X_{in}=0$
D=0,918 cm
G=219 gr/cm^2 sec

Fig. 18



P=72 ata $X_{in}=0$

G=219 gr/cm^{2}sec L=139,9 cm

Fig. 19

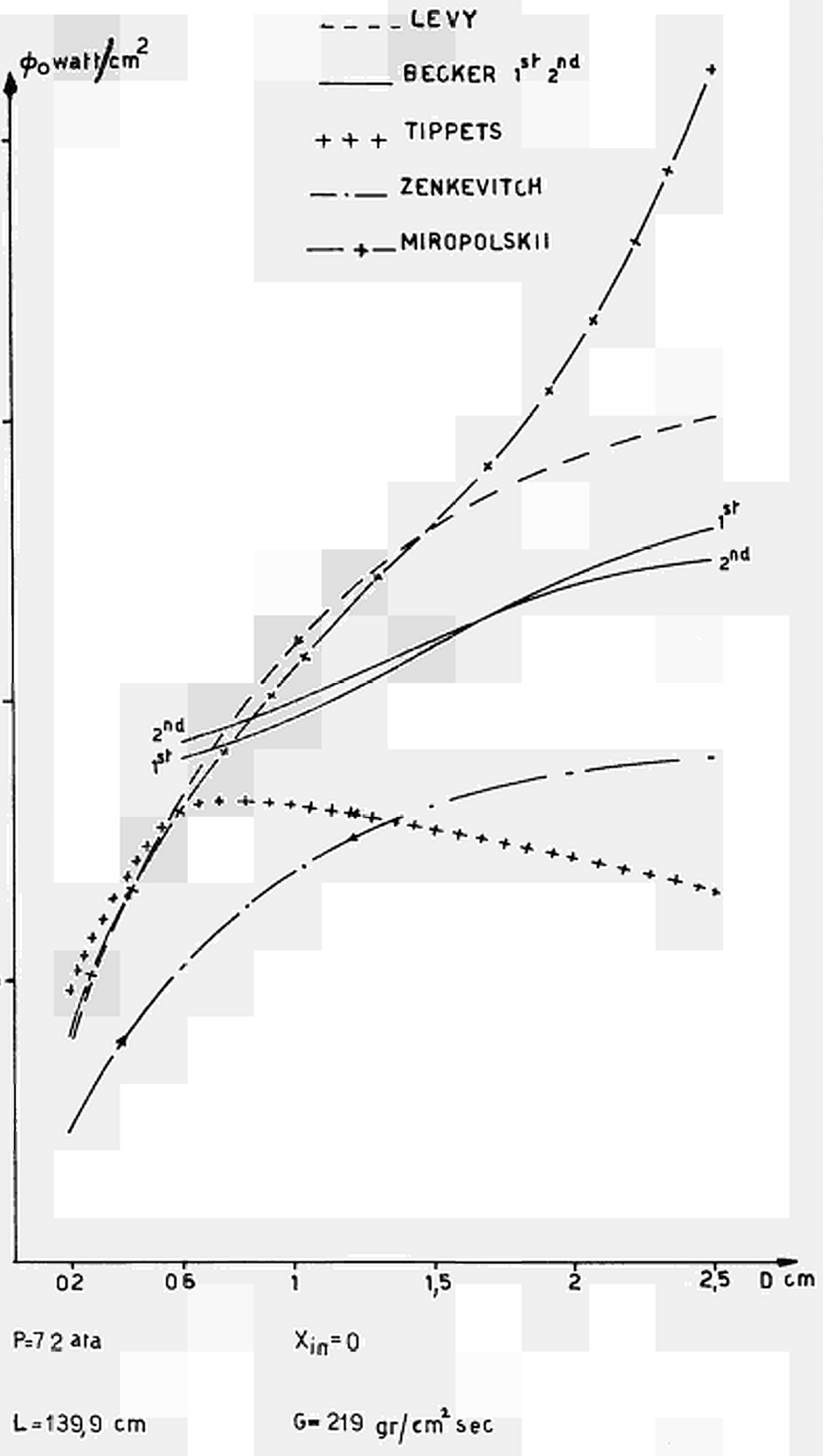
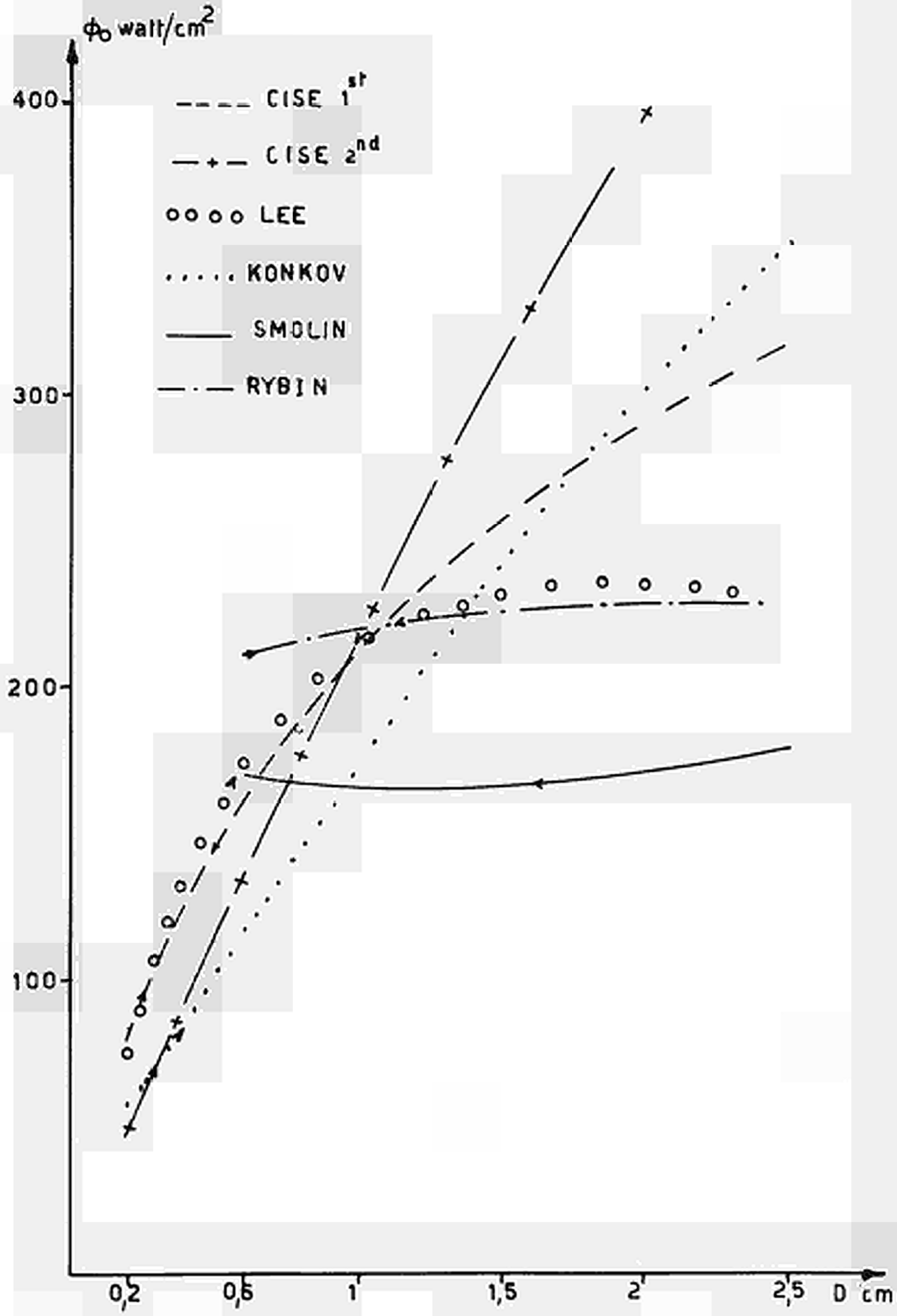

ϕ_0 watt/cm^2
LEVY
BECKER 1st 2nd
TIPPETS
ZENKEVITCH
MIROPOLSKII
400
300
200
100
1st
2nd
2nd
1st
0,2
0,6
1
1,5
2
2,5
D cm
P=7,2 ata
$X_{in}=0$
L=139,9 cm
G= 219 gr/cm^2 sec

Fig. 20



P = 72 ata $X_{in} = 0$

G = 219 gr/cm²sec   L = 139,9 cm

Fig. 21

WATER PHYSICAL PROPERTIES

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

$$\Theta = 118{,}052 \cdot P^{0{,}22151} - 17{,}778$$

$$H_s = 408{,}86 \cdot P^{0{,}26452} \qquad \text{for} \quad 7 < P < 70$$

$$H_s = 337{,}73 \cdot P^{0{,}30934} \qquad \text{for} \quad 70 \leq P < 140$$

$$H_{eg} = 2144{,}8987 - 13{,}4 \cdot P + 8{,}07524 \cdot 10^{-2} \cdot P^2 - 2{,}82159 \cdot 10^{-4} \cdot P^3$$

$$\nu_{eg} = \frac{1{,}87903 \cdot 10^3}{P} - 7{,}866 \qquad \text{for} \quad 7 < P \leq 21$$

$$\nu_{eg} = \frac{2{,}3 \cdot 10^3}{P} - 6{,}242 \qquad 21 < P < 140$$

$$\rho_e = 1{,}022078 - 4{,}9862 \cdot 10^{-4} \cdot \Theta + 3{,}3705 \cdot 10^{-7} \cdot \Theta^2 - 6{,}33927 \cdot 10^{-9}\, \Theta^3$$

$$\sigma = 70{,}043 \cdot (\rho_e - \rho_g)^4$$

$$\mu_e = \frac{10^{-2}}{3{,}7 \cdot 10^{-2} \cdot \Theta - 0{,}22282}$$

$$\mu_g = 0{,}56478 \cdot 10^{-4} + 0{,}524722 \cdot 10^{-6} \cdot \Theta + \frac{4{,}21847 \cdot 10^{-4}}{\Theta - 374{,}5}$$

$$C_e = -8{,}32376 + 0{,}1811 \cdot \Theta - 0{,}8582 \cdot 10^{-3} \cdot \Theta^2 + 1{,}371 \cdot 10^{-6} \cdot \Theta^3$$

$$k = 0{,}41688 \cdot 10^{-15} \cdot \Theta^5 - 0{,}35633 \cdot 10^{-12} \cdot \Theta^4 + 0{,}180574 \cdot 10^{-5} \cdot \Theta + 6{,}705 \cdot 10^{-3}$$

B I B L I O G R A P H Y

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NOMENCLATURE

Symbol	Definition	Units	
D	equivalent diameter $\frac{4S}{P}$	cm.	L
D_{he}	equivalent heated diameter $\frac{4S}{P_{he}}$	cm	L
G	mass velocity	$\frac{g}{cm^2\,sec}$	$M\,L^{-2}\,T^{-1}$
H_{gl}	enthalpy of vaporization	$\frac{joule}{g}$	$L^2\,T^{-2}$
H_s	saturation enthalpy	$\frac{joule}{g}$	$L^2\,T^{-2}$
L	heated length	cm	L
L_s	saturation length	cm	L
N_u	Nusselt number	dimensionless	-
P	absolute pressure	ata	$M\,L^{-1}\,T^{-2}$
P_{crit}	critical pressure	ata	$M\,L^{-1}\,T^{-2}$
P_r	Prandtl number =	dimensionless	-
R_e	Reynolds number=	dimensionless	-
S	flow aerea	cm^2	L^2
W	power	watt	$M\,L^2\,T^{-3}$
W_s	saturation power	watt	$M\,L^2\,T^{-3}$
X_e	outlet quality	dimensionless	-
X_{in}	inlet quality	dimensionless	-
C_l	liquid specific heat	$\frac{joule}{g\,^\circ C}$	$L^2\,T^{-2}$
C_g	vapor specific heat	$\frac{joule}{g\,^\circ C}$	$L^2\,T^{-2}$

Symbol	Definition	Units	
g	acceleration due to gravity	$\frac{cm}{sec^2}$	LT^{-2}
k	thermal conductivity	$\frac{watt}{cm\ ^\circ C}$	MLT^{-3}
P	wetted wall area per unit duct length	cm	L
P_{he}	heated wall area per unit duct length	cm	L
Θ	saturation temperature	°C	-
μ	dinamic viscosity	g/cm sec	$M L^{-1}T^{-1}$
v_g	vapor specific volume	cm^3 / g	$M^{-1}L^3$
v_L	liquid specific volume	cm^3 / g	$M^{-1}L^3$
v_{Lg}	differential evaporation volume	cm^3 / g	$M^{-1}L^3$
v	$\frac{v_L}{v_{Lg}}$	dimensionless	-
ρ_g	vapor density	g / cm^3	ML^{-3}
ρ_L	liquid density	g / cm^3	ML^{-3}
σ	surface tension	dine/cm	$M T^{-2}$
ϕ_o	critical heat flux	watt/cm^2	$M T^{-3}$
ϕ_{TPF}	two-phase friction factor	dimensionless	-
δ	gap	cm	L
ΔT_{sub}	inlet subcooling	°C	-

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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