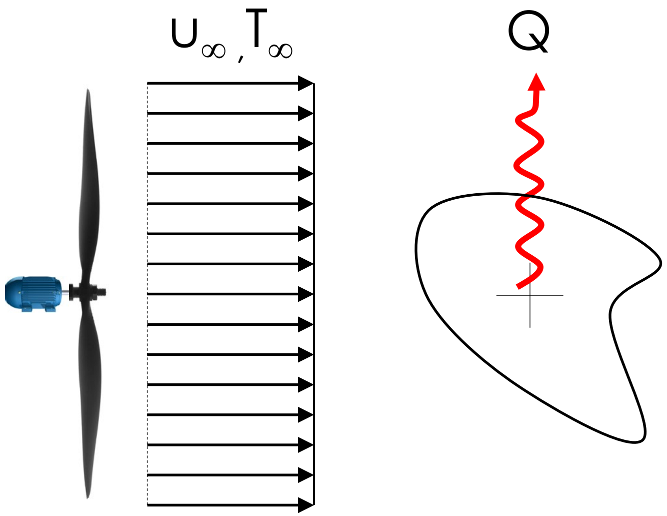
CORRELAÇÕES EMPÍRICAS PARA O CÁLCULO DO NÚMERO DE NUSSELT EM ESCOAMENTOS CONVECTIVOS

Aulas 1 – 3 do módulo TC



$$Q = hA_{lateral} \cdot (T - T_\infty)$$

$$Nu = C \cdot Re^m \cdot Pr^{1/3}$$

$$\text{properties @ } T_{fluid} = \left(\frac{T_s + T_\infty}{2} \right)$$

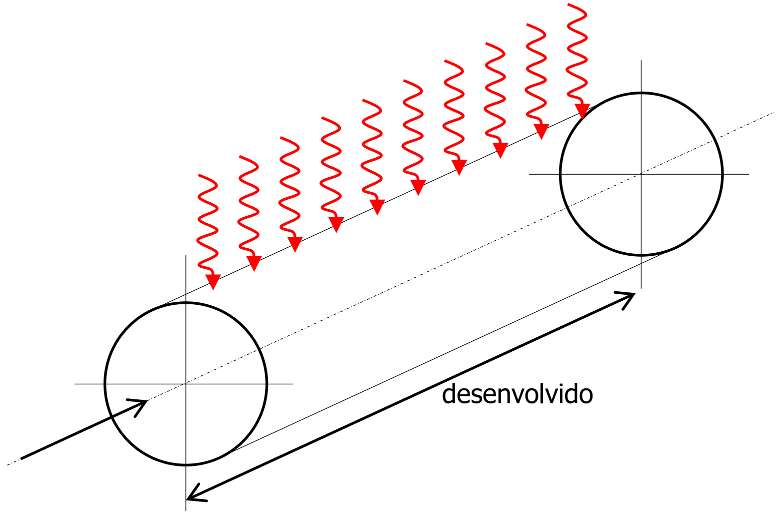
batman

Avaliação P2

Empirical correlations for the average Nusselt number for forced convection over circular and noncircular cylinders in cross flow (from Zukauskas, Ref. 14, and Jakob, Ref. 6)

Cross-section of the cylinder	Fluid	Range of Re	Nusselt number
Circle	Gas or liquid	0.4–4 4–40 40–4000 4000–40,000 40,000–400,000	$Nu = 0.989Re^{0.330}\ Pr^{1/3}$ $Nu = 0.911Re^{0.385}\ Pr^{1/3}$ $Nu = 0.683Re^{0.466}\ Pr^{1/3}$ $Nu = 0.193Re^{0.618}\ Pr^{1/3}$ $Nu = 0.027Re^{0.805}\ Pr^{1/3}$
Square	Gas	5000–100,000	$Nu = 0.102Re^{0.675}\ Pr^{1/3}$
Square (tilted 45°)	Gas	5000–100,000	$Nu = 0.246Re^{0.588}\ Pr^{1/3}$
Hexagon	Gas	5000–100,000	$Nu = 0.153Re^{0.638}\ Pr^{1/3}$
Hexagon (tilted 45°)	Gas	5000–19,500 19,500–100,000	$Nu = 0.160Re^{0.638}\ Pr^{1/3}$ $Nu = 0.0385Re^{0.782}\ Pr^{1/3}$
Vertical plate	Gas	4000–15,000	$Nu = 0.228Re^{0.731}\ Pr^{1/3}$
Ellipse	Gas	2500–15,000	$Nu = 0.248Re^{0.612}\ Pr^{1/3}$

Correlações para escoamentos internos...



$$Re = \frac{\rho u_0 D}{\mu} \qquad Pr = \frac{C_p \mu}{k}$$

Escoamento laminar:

Fluxo de calor constante: $Nu = 4.36$

Temperatura constante: $Nu = 3.66$

Escoamento turbulento desenvolvido (Re > 10^4):

Superfície lisa: $Nu = 0.023 \cdot Re^{4/5} \cdot Pr^n$

(Dittus-Boelter)

$n = 0.3 \;\; p/ \; T_s < T_m$

$n = 0.4 \;\; p/ \; T_s > T_m$

$$\left[\begin{array}{l} 0.7 \lesssim Pr \lesssim 160 \\ Re_D \gtrsim 10{,}000 \\ \frac{L}{D} \gtrsim 10 \end{array} \right]$$


HOMEM DE FERRO

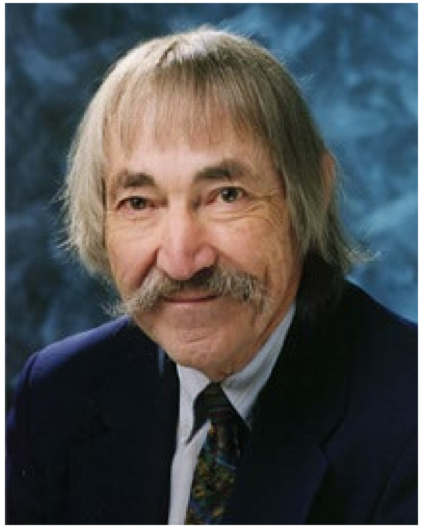
Avaliação P2

Superfície rugosa:

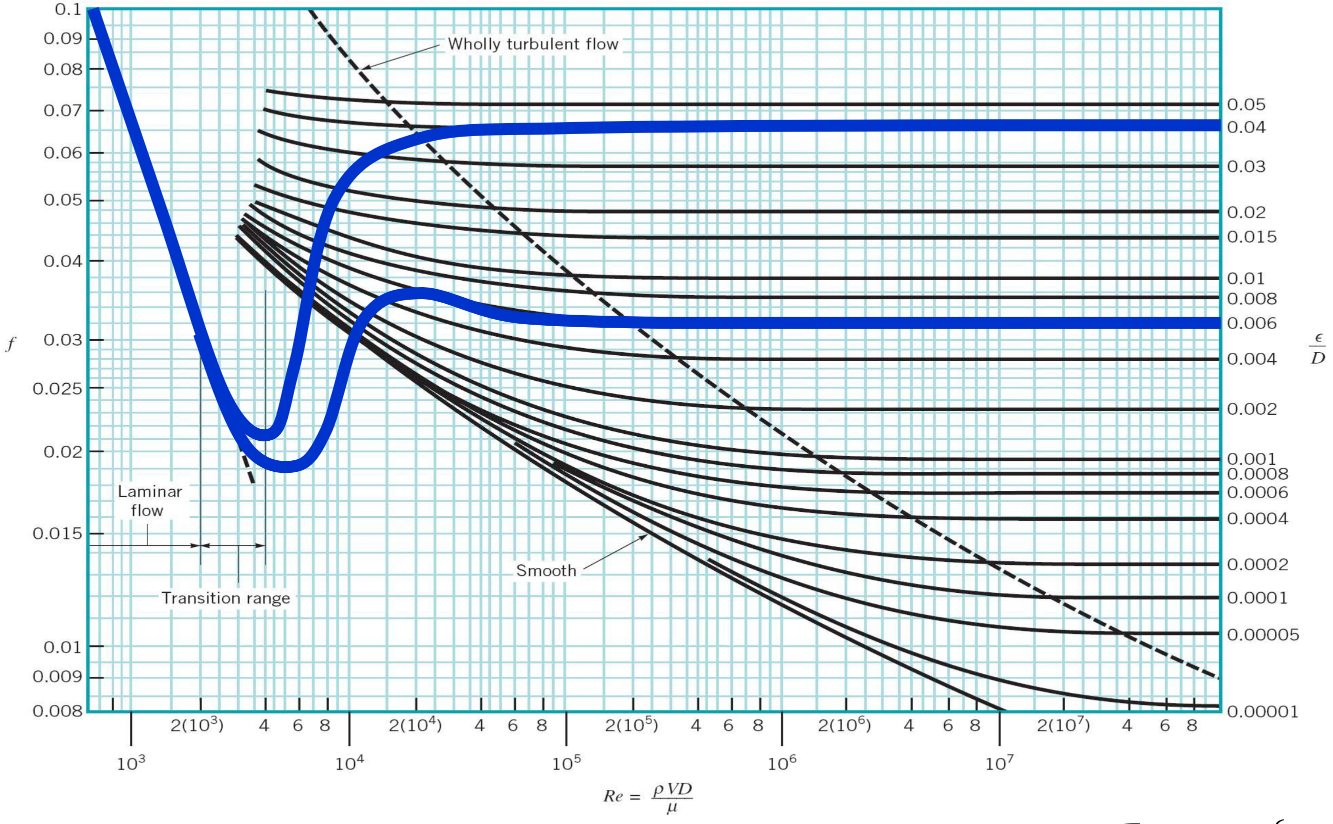
$$Nu = \frac{f}{8} \cdot \frac{(Re - 1000) \cdot Pr}{1 + 12.7 (f/8)^{1/2} (Pr^{2/3} - 1)}$$

f = friction factor

A equação de Darcy e cálculo do fator de atrito...

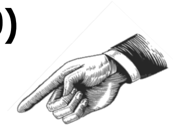


Stuart W. Churchill



Laminar (Re < 2500)

$$f = \frac{64}{Re}$$



HOMEM ARANHA

Turbulento (Re > 4000)

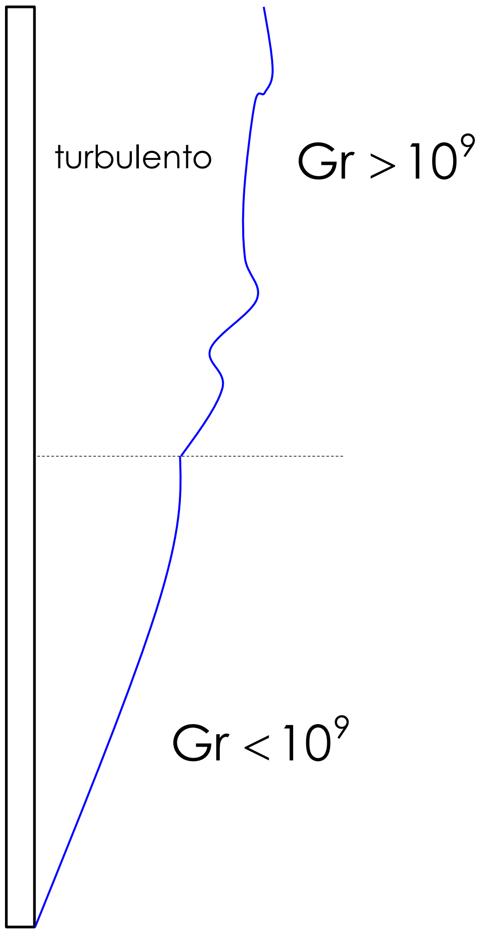
Colebrook-White

$$\frac{1}{\sqrt{f}} = -2\log\left(3.7\frac{e}{D} + \frac{2.51}{Re\sqrt{f}}\right)$$

$$f = 8\cdot\left[\left(\frac{8}{Re}\right)^{12} + (A+B)^{-1,5}\right]^{1/12}$$

$$A = \left\{2,457\ln\left(\left(\left(\frac{7}{Re}\right)^{0,9} + 0,27\cdot\frac{\varepsilon}{D}\right)^{-1}\right)\right\}^{16}$$

$$B = \left(\frac{37530}{Re}\right)^{16} \qquad Re = \frac{4\cdot m}{\mu\,\pi D}$$



Avaliação P2

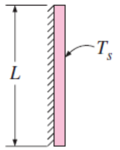
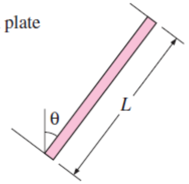
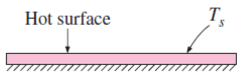
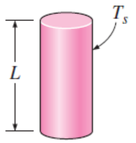
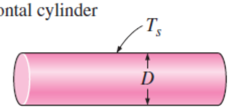
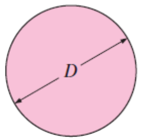
MULHER-MARAVILHA

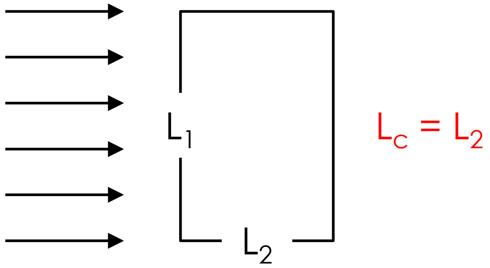
$$Q = hA_{lateral} \cdot (T - T_\infty)$$

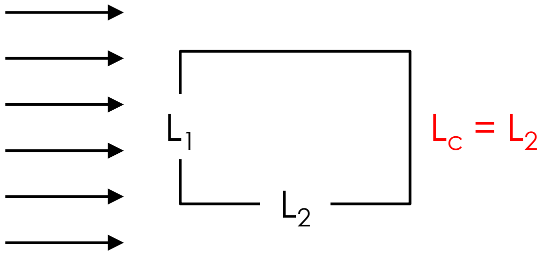
$$Nu = C \cdot Ra^n$$

$$\text{properties @ } T_{fluid} = \left(\frac{T_s + T_\infty}{2}\right)$$

Empirical correlations for the average Nusselt number for natural convection over surfaces

Geometry	Characteristic length L_c	Range of Ra	Nu
Vertical plate 	L	10^4–10^9 10^9–10^{13} Entire range	$Nu = 0.59Ra_L^{1/4}$ (9-19) $Nu = 0.1Ra_L^{1/3}$ (9-20) $Nu = \left\{0.825 + \frac{0.387Ra_L^{1/6}}{[1 + (0.492/Pr)^{9/16}]^{8/27}}\right\}^2$ (9-21) (complex but more accurate)
Inclined plate 	L		Use vertical plate equations for the upper surface of a cold plate and the lower surface of a hot plate Replace g by $g \cos\theta$ for $Ra < 10^9$
Horiontal plate (Surface area A and perimeter p) (a) Upper surface of a hot plate (or lower surface of a cold plate)  (b) Lower surface of a hot plate (or upper surface of a cold plate) 	A_s/p	10^4–10^7 10^7–10^{11} 10^5–10^{11}	$Nu = 0.54Ra_L^{1/4}$ (9-22) $Nu = 0.15Ra_L^{1/3}$ (9-23) $Nu = 0.27Ra_L^{1/4}$ (9-24)
Vertical cylinder 	L		A vertical cylinder can be treated as a vertical plate when $D \geq \frac{35L}{Gr_L^{1/4}}$
Horizontal cylinder 	D	$Ra_D \leq 10^{12}$	$Nu = \left\{0.6 + \frac{0.387Ra_D^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}\right\}^2$ (9-25)
Sphere 	D	$Ra_D \leq 10^{11}$ ($Pr \geq 0.7$)	$Nu = 2 + \frac{0.589Ra_D^{1/4}}{[1 + (0.469/Pr)^{9/16}]^{4/9}}$ (9-26)





Avaliação P2

HULK

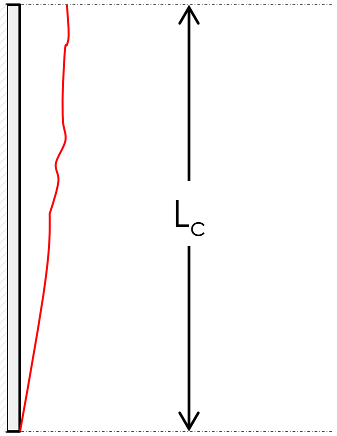
Table 2. Empirical correlations for the average Nusselt number for forced convection over isothermal surfaces. The characteristic length, L_c, is defined in Section 3.1.3.

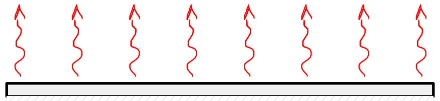
Geometry	L_c	Range of Validity	Nu
Parallel to a plate			
Laminar flow	L	$Re \leq 5 \times 10^5$ $0.6 \leq Pr \leq 60$	$Nu = 0.664Re^{1/2}Pr^{1/3}$ [33]
Turbulent flow	L	$5 \times 10^5 \leq Re \leq \times 10^7$ $0.6 \leq Pr \leq 60$	$Nu = 0.037Re^{4/5}Pr^{1/3}$ [33]
Combined flow	L	$5 \times 10^5 \leq Re \leq \times 10^7$ $0.6 \leq Pr \leq 60$	$Nu = (0.037Re^{4/5} - 871)Pr^{1/3}$ [33]
Around a sphere	D	$0 \leq Re < 200$ $0 \leq Pr \leq 250$	$Nu = 2 + 0.6Re^{1/2}Pr^{1/3}$ [35]

[33] Welty, J.; Rorrer, G.L.; Foster, D.G. Fundamentals of Momentum, Heat and Mass Transfer; John Wiley & Sons: New York, NY, USA, 2014.
[35] Ranz, W.E.; Marshall, W.R. Evaporation from Drops. Chem. Eng. Prog. 1952, 48, 141–146.

Avaliação P2

CAPITÃO AMÉRICA





L_c = Area/perímetro

Table 3. Empirical correlations for the average Nusselt number for natural convection over isothermal surfaces. The characteristic length, L_c, is defined in Section 3.1.3.

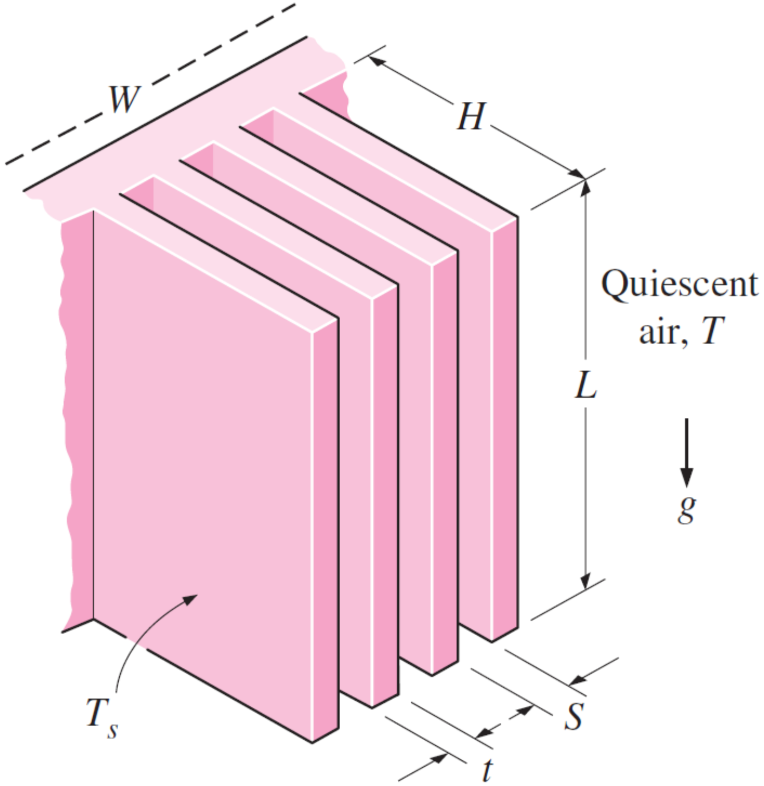
Geometry	L_c	Range of Validity	Nu
Vertical plate			
Laminar flow	L	$10^4 \leq Ra \leq 10^9$	$Nu = 0.59Ra^{1/4}$ [32]
Turbulent flow	L	$10^9 \leq Ra \leq 10^{13}$	$Nu = 0.1Ra^{1/3}$ [32]
Any type of flow	L	$Ra \leq 10^{12}$	$Nu = \left(0.825 + \frac{0.387Ra^{1/6}}{(1+(0.492/Pr)^{9/16})^{8/27}}\right)^2$ [36]
Horizontal plate			
Laminar flow	A_s/p	$10^4 \leq Ra \leq 10^7$	$Nu = 0.54Ra^{1/4}$ [32]
Turbulent flow	A_s/p	$10^7 \leq Ra \leq 10^{11}$	$Nu = 0.15Ra^{1/3}$ [32]
Sphere	D	$Ra \leq 10^{11}$, $Pr \geq 0.7$	$Nu = 2 + \frac{0.589Ra^{1/4}}{(1+(0.469/Pr)^{9/16})^{4/9}}$ [37]

[32] McAdams, W.H. Heat Transmission; McGraw-Hill Book Company: New York, NY, USA, 1957.

[36] Churchill, S.W.; Chu, H.H.S. Correlating Equations for Laminar and Turbulent Free Convection from a Vertical Plate. Int. J. Heat Mass Transf. 1975, 18, 1323–1329. [CrossRef]

[37] Churchill, S.W. Free Convection around Immersed Bodies. In Heat Exchanger Design Handbook; Hemisphere Publishing: New York, NY, USA, 1983.

Convecção natural em superfícies aletadas @ T_s = cte ...



$$Ra_S = \frac{g\beta(T_s - T_\infty)\cdot S^3}{\nu^2}Pr \quad \text{ou} \quad Ra_L = \frac{g\beta(T_s - T_\infty)\cdot L^3}{\nu^2}Pr$$

$$Nu = \frac{hS_{opt}}{k} = \left[\frac{576}{(Ra_S \cdot S/L)^2} + \frac{2.873}{(Ra_S \cdot S/L)^{0.5}}\right]^{-0.5}$$

Avaliação P2

Bar-Cohen and Rohsenow

Espaçamento ótimo (trade-off área x vazão):

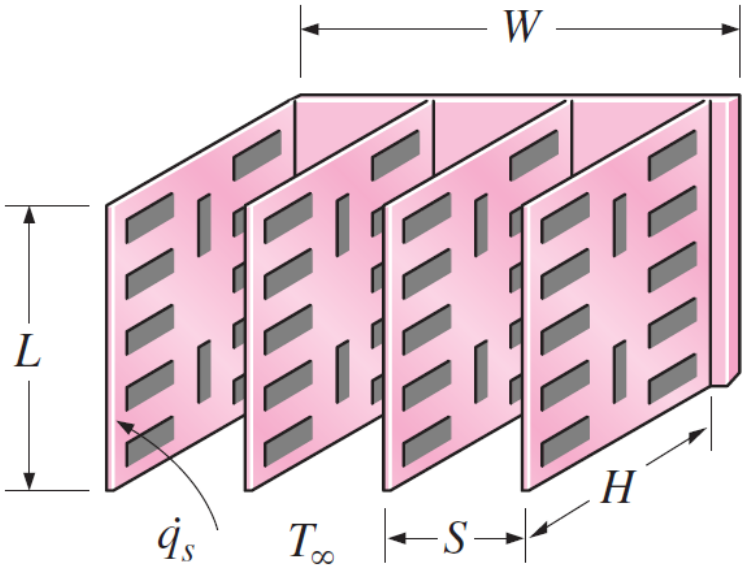
AQUAMAN

$$@\ T_s = cte \rightarrow S_{opt} = 2.714\frac{L}{Ra_L^{0.25}} \rightarrow Nu = 1.307$$

$$Q = h\cdot(2nLH)\cdot(T_s - T_\infty) \quad \leftarrow \; t << S$$

$$\text{properties } @\ T_{avg} = (T_s + T_\infty)/2$$

Convecção natural em superfícies aletadas @ q_s = cte ...



$$Ra_S = \frac{g\beta q_s \cdot S^4}{k\nu^2} Pr$$

$$Nu = \frac{hL}{k} = \left[\frac{48}{Ra_S \cdot S/L} + \frac{2.51}{(Ra_S \cdot S/L)^{0.4}} \right]^{-0.5}$$

Avaliação P2

Bar-Cohen and Rohsenow

TARTARUGA NINJA

Espaçamento ótimo (trade-off área x vazão):

$$@\ q_s = cte \rightarrow S_{opt} = 2.12 \cdot \left(\frac{S^4 L}{Ra_S} \right)^{0.2}$$

$$Q = q_s \cdot (2nLH) \quad \leftarrow t \ll S$$

$$\text{properties } @\ T_{avg} = (T_L + T_\infty)/2 \quad \leftarrow T_L = T_\infty + q_s / h$$

temperatura crítica ocorrendo na borda superior