Formulário

- **Equação da Hidrostática**

$$\rho\vec{g} = \Delta P \qquad \frac{dP}{dz} = -\rho g$$

- **Análise integral do escoamento laminar**

Conservação da massa $$\iint (\vec{v}\cdot\vec{n})\rho dA + \frac{\partial}{\partial t}\iiint \rho dV = 0$$

Conservação da q.d.m. $$\sum \vec{F} = \iint (\vec{v}\cdot\vec{n})\rho\vec{v}dA + \frac{\partial}{\partial t}\iiint \rho\vec{v}dV$$

Conservação da energia $$\frac{\delta Q}{dt} - \frac{\delta W_s}{dt} = \iint \left(e + \frac{P}{\rho}\right)\rho(\vec{v}\cdot\vec{n})dA + \frac{\partial}{\partial t}\iiint e\rho dV + \frac{\delta W_\mu}{dt}$$

Eq. de BERNOULLI : $$y + \frac{v^2}{2g} + \frac{P}{\rho g} = \text{const.}$$

- **Lei de Newton do atrito**

$$\tau = \mu\frac{dv}{dy}$$

- **Análise diferencial do escoamento laminar**

Eq. de Hagen-Poiseuille: $$-\frac{dP}{dx} = \frac{32\mu v_{med}}{D^2}$$ (tubo circular horizontal)

Diâmetro hidráulico $$D_H = \frac{4\cdot S}{P_{molhado}}$$

- **Potência útil**

$$W_u = Q\cdot\rho\cdot g\cdot h$$

- **Equações diferenciais básicas**

Continuidade: $$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\vec{v}) = 0$$

Cons. da q.d.m.: $$\rho\frac{D\vec{v}}{Dt} = \rho\vec{g} - \nabla P + \mu\nabla^2\vec{v}$$ Eq.s Navier-Stokes (ρ e μ constantes)

- **Alguns números adimensionais**

$$Re = \frac{\rho L v}{\mu} \qquad Fr = \frac{v^2}{gL} \qquad Eu = \frac{P_a}{\rho v^2} \qquad Ma = \frac{v}{a} \qquad C_d = \frac{F_{arrasto}}{(1/2)\rho v^2 A}$$

- **Perfil universal de velocidades**

zona turbulenta:	$y^+ \geq 30$	$v^+ = 5,5 + 2,5 \ln y^+$
zona tampão:	$30 > y^+ \geq 5$	$v^+ = -3,05 + 5,0 \ln y^+$
sub-camada laminar:	$5 > y^+ > 0$	$v^+ = y^+$

$$y^+ = \frac{u_* y}{\nu}$$

$$v^+ = \frac{\bar{v}_x}{u_*}$$

$$u_* = \sqrt{(\tau_0/\rho)}$$

- **Equações da camada limite (c. l.)**

Laminar ($Re_x < 2 \times 10^5$)

$$\frac{\delta}{x} = \frac{5}{Re_x^{1/2}} \qquad \frac{\delta^*}{x} = \frac{1{,}721}{Re_x^{1/2}} \qquad C_{fL} = \frac{1{,}328}{Re_L^{1/2}} \qquad \tau_0 = \frac{0{,}332\rho^{1/2}\mu^{1/2}v_\infty^{3/2}}{x^{1/2}}$$

Turbulenta ($Re_x > 3 \times 10^6$)

$$\frac{\delta}{x} = \frac{0{,}376}{Re_x^{1/5}} \qquad \delta^* = \frac{\delta}{8} \qquad C_{fL} = \frac{0{,}074}{Re_L^{1/5}} \qquad \tau_0 = \frac{0{,}0135\rho^{6/7}\mu^{1/7}v_\infty^{13/7}}{x^{1/7}}$$

$$Re_x = \frac{v_\infty x}{\nu}$$

- **Perdas de carga em escoamentos em condutas fechadas**

Perdas de carga em linha: $h_L = 2f\frac{L}{D}\frac{v^2}{g}$ — f = coef. de atrito de fanning (D. Moody)

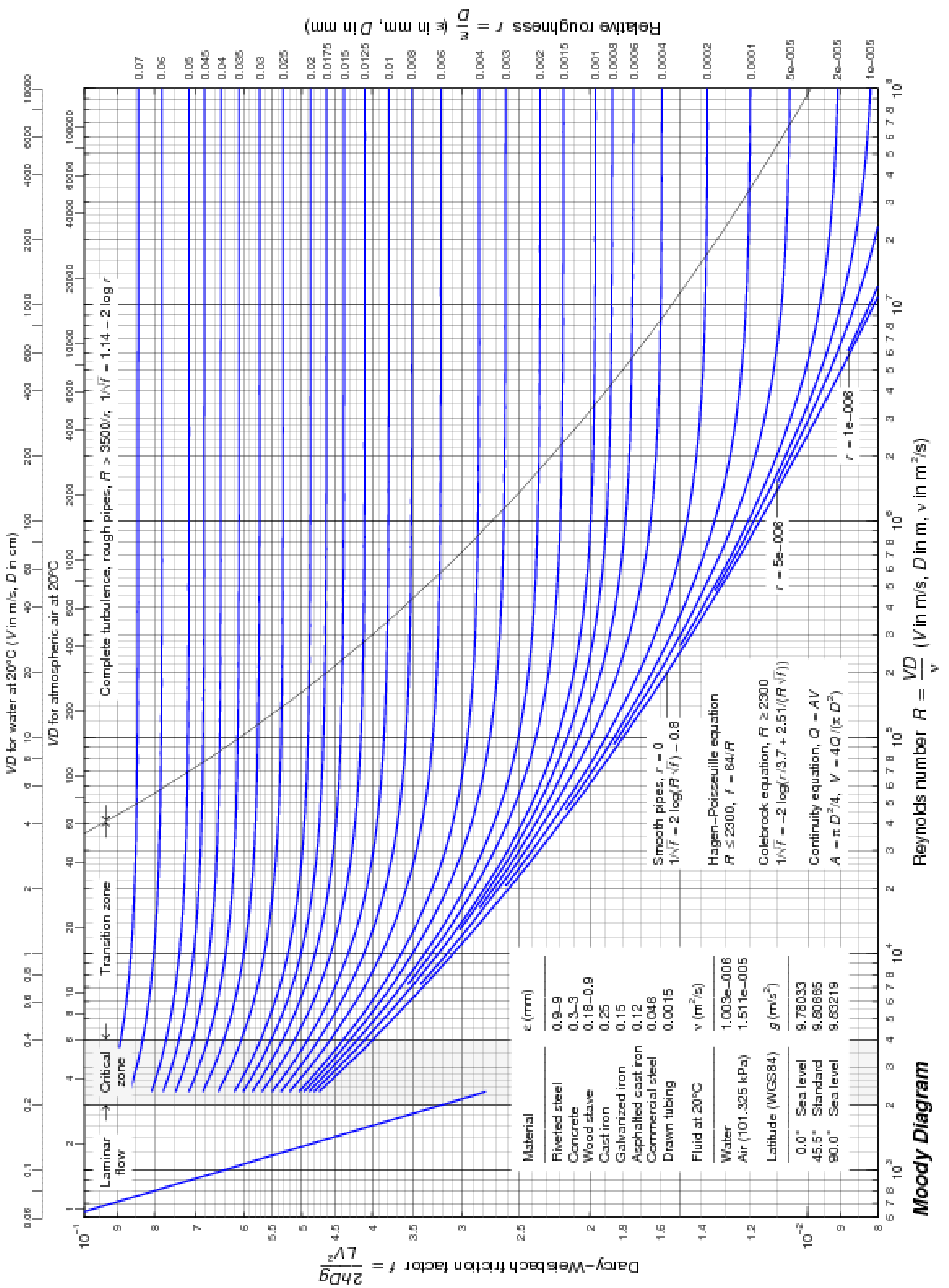
Perdas de carga em linha: $h_L = f_D\frac{L}{D}\frac{v^2}{2g}$ — f_D = coef. de atrito de Darcy (D. Moody)

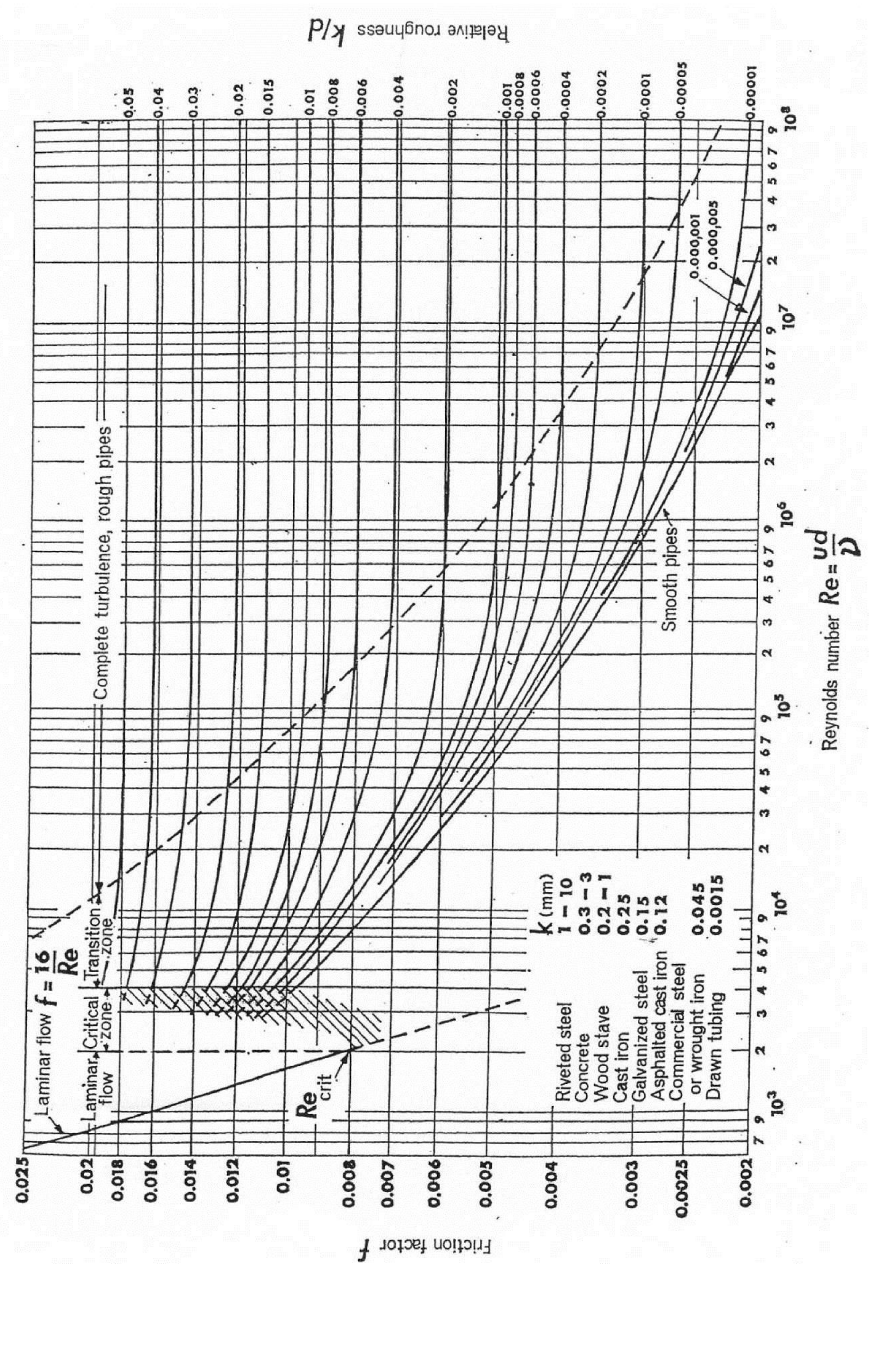
Perdas de carga localizadas: $h_l = K\frac{v^2}{2g}$ — K = coef. de perda localizada

- **Medição de escoamentos**

$$Q = A_t C_d \left[\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}\right]^{1/2}$$

C_d = coef. de descarga $\qquad \beta = d/D$


Moody Diagram
Relative roughness $r = \frac{\varepsilon}{D}$ (ε in mm, D in mm)
Darcy–Weisbach friction factor $f = \frac{2hDg}{LV^2}$
Reynolds number $R = \frac{VD}{\nu}$ (V in m/s, D in m, ν in m^2/s)
VD for water at 20°C (V in m/s, D in cm)
VD for atmospheric air at 20°C
Complete turbulence, rough pipes, $R > 3500/r$, $1/\sqrt{f} = 1.14 - 2\log r$
Laminar flow
Critical zone
Transition zone
Smooth pipes, $r = 0$
$1/\sqrt{f} = 2\log(R\sqrt{f}) - 0.8$
Hagen–Poiseuille equation
$R \le 2300$, $f = 64/R$
Colebrook equation, $R \ge 2300$
$1/\sqrt{f} = -2\log(r/3.7 + 2.51/(R\sqrt{f}))$
Continuity equation, $Q = AV$
$A = \pi D^2/4$, $V = 4Q/(\pi D^2)$
$r = 5e-006$
$r = 1e-006$
Material | ε (mm)
Riveted steel | 0.9–9
Concrete | 0.3–3
Wood stave | 0.18–0.9
Cast iron | 0.26
Galvanized iron | 0.15
Asphalted cast iron | 0.12
Commercial steel | 0.046
Drawn tubing | 0.0015
Fluid at 20°C | ν (m^2/s)
Water | 1.003e–006
Air (101.325 kPa) | 1.511e–005
Latitude (WGS84) | g (m/s^2)
0.0° Sea level | 9.78033
45.5° Standard | 9.80665
90.0° Sea level | 9.83219


Friction factor f
Reynolds number Re = ud/ν
Relative roughness k/d
Laminar flow f = 16/Re
Laminar flow
Critical zone
Transition zone
Complete turbulence, rough pipes
Re crit
Smooth pipes
0.000,001
0.000,005
k (mm)
Riveted steel 1 – 10
Concrete 0.3 – 3
Wood stave 0.2 – 1
Cast iron 0.25
Galvanized steel 0.15
Asphalted cast iron 0.12
Commercial steel or wrought iron 0.045
Drawn tubing 0.0015
0.025
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.007
0.006
0.005
0.004
0.003
0.0025
0.002
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.00005
0.00001
10³
10⁴
10⁵
10⁶
10⁷
10⁸

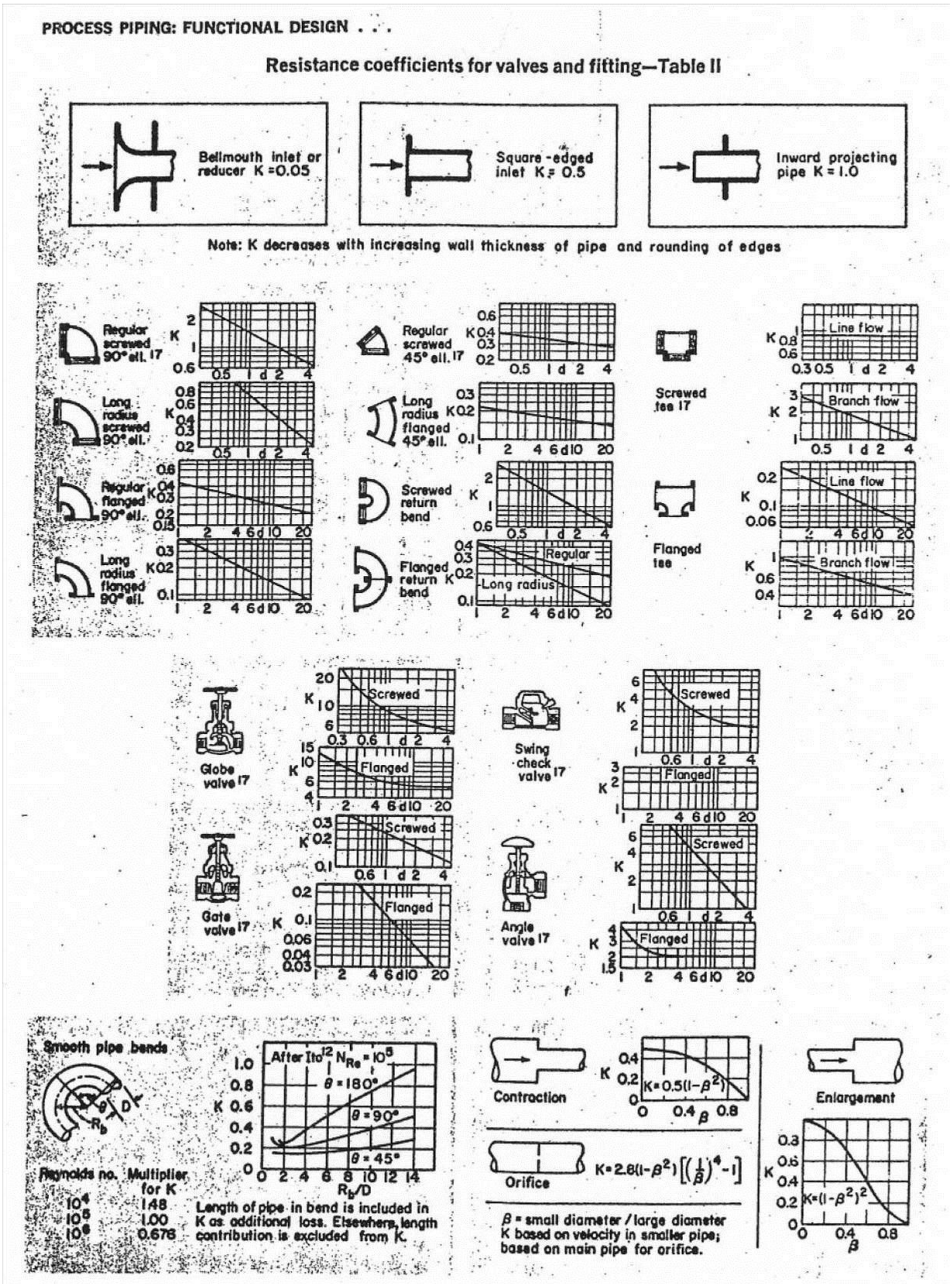
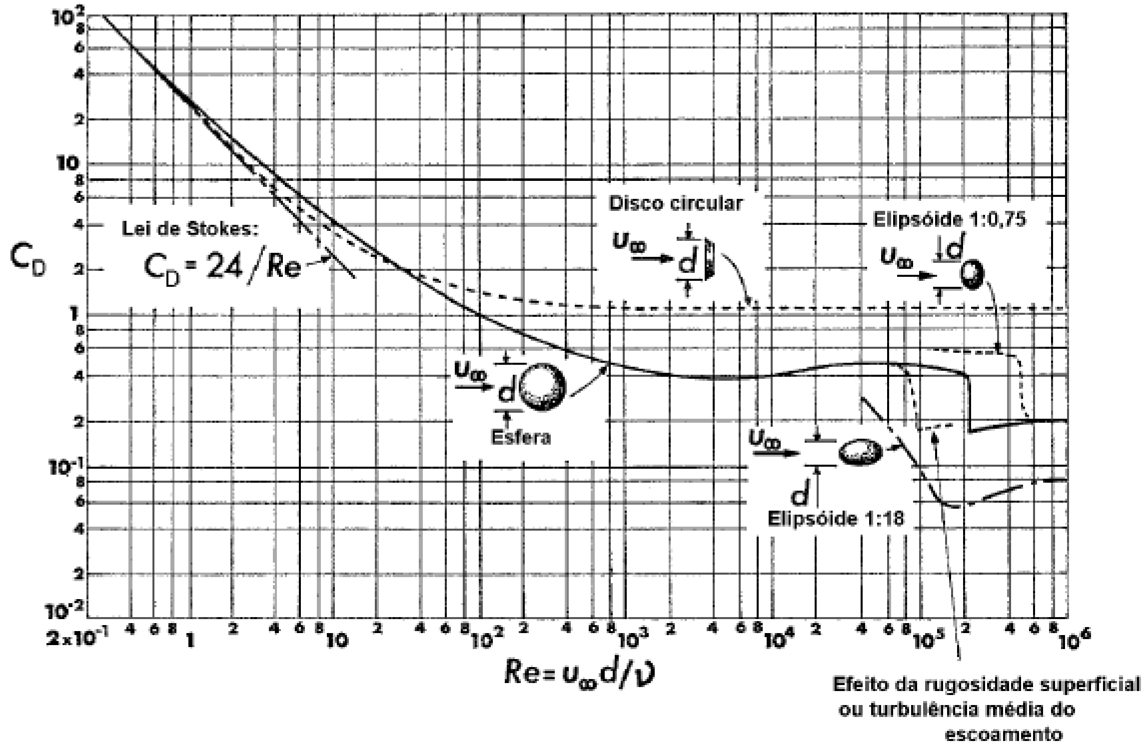
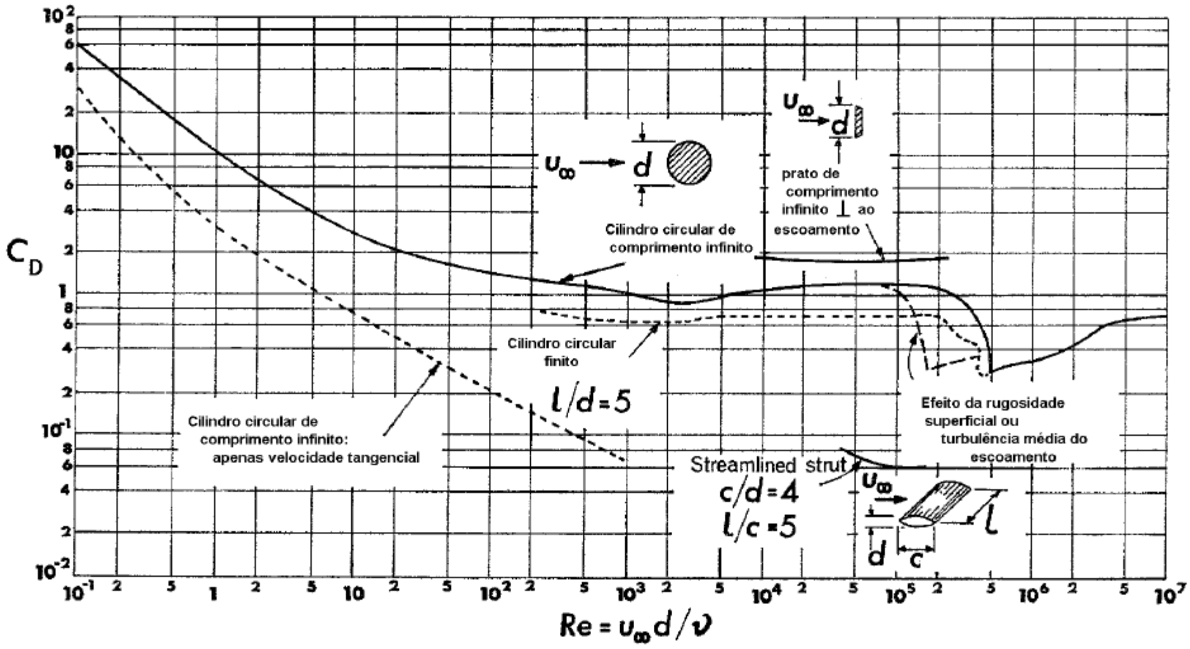


Figura 8.3: Perdas de carga localizadas para cotovelos, válvulas, convergentes, difusores e zonas de entrada em condutas (em polegadas).



Coeficientes de arrasto para corpos axi-simétricos (superfícies lisas)



Coeficientes de arrasto para corpos bidimensionais