$\dot{m} = \rho u_m A_c$ $\quad \dot{m}$ Mass flow rate

A_c cross-sectional area

$$Re_D = \frac{4\dot{m}}{\pi D \mu}$$

Fully developed velocity profile

$$\frac{u(r)}{u_m} = 2\left(1 - \left(\frac{r}{r_0}\right)^2\right)$$

Friction Factor

Laminar Flow $f = \frac{64}{Re_D}$

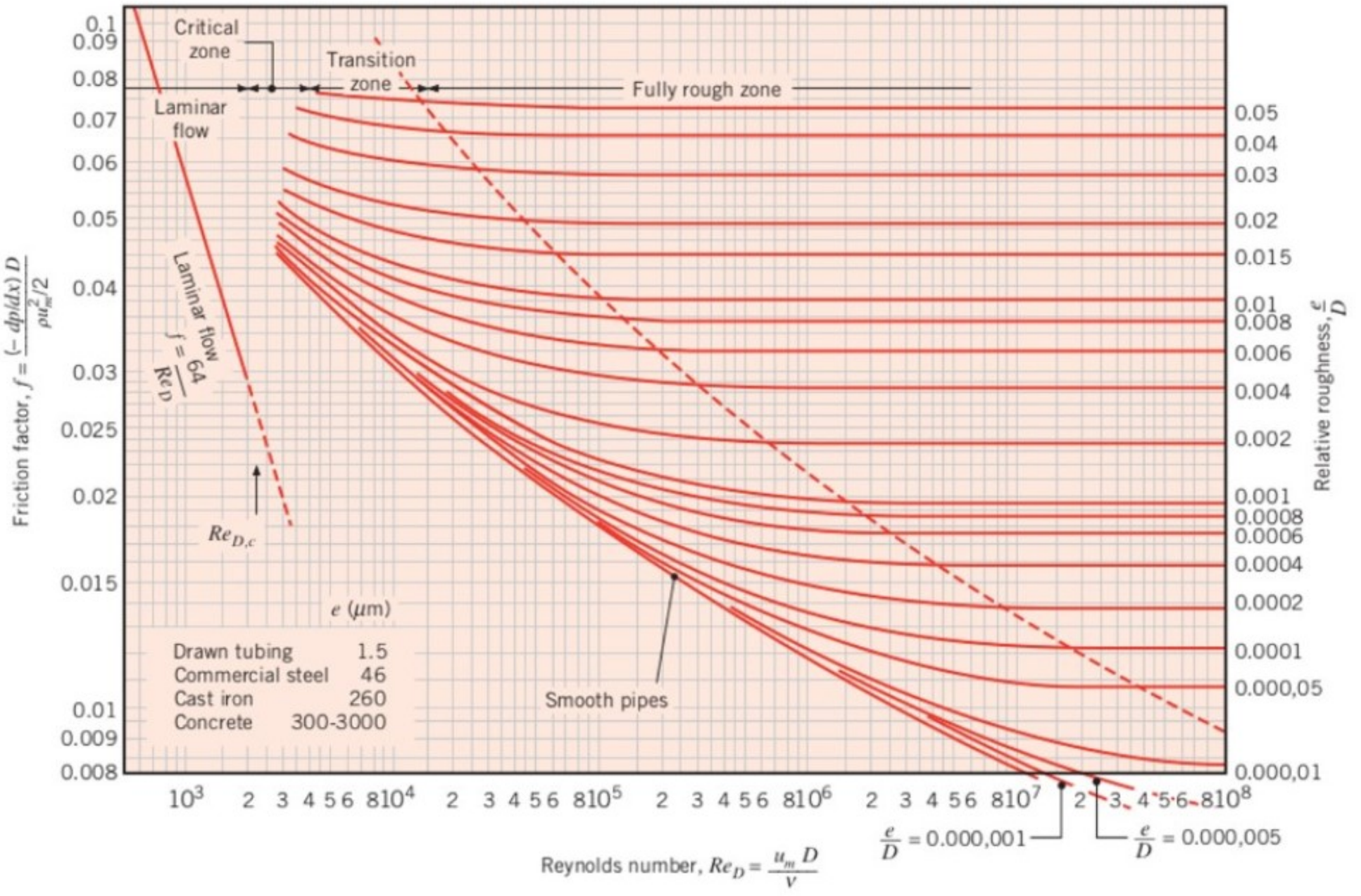
Turbulent

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

for smooth pipe

$$f = (0.79\ln(Re_D) - 1.64)^{-2} \qquad 3000 < Re_D < 5\times10^6$$

Fig 8.3


Critical zone
Transition zone
Fully rough zone
Laminar flow
Laminar flow $f = \frac{64}{Re_D}$
$Re_{D,c}$
Smooth pipes
e (μm)
Drawn tubing 1.5
Commercial steel 46
Cast iron 260
Concrete 300-3000
Friction factor, $f = \frac{(-dp/dx)D}{\rho u_m^2/2}$
Relative roughness, $\frac{e}{D}$
Reynolds number, $Re_D = \frac{u_m D}{\nu}$
$\frac{e}{D} = 0.000,001$
$\frac{e}{D} = 0.000,005$

Pressure Drop

$$\Delta p = f \frac{\rho u_m^2}{2D} (x_2 - x_1)$$

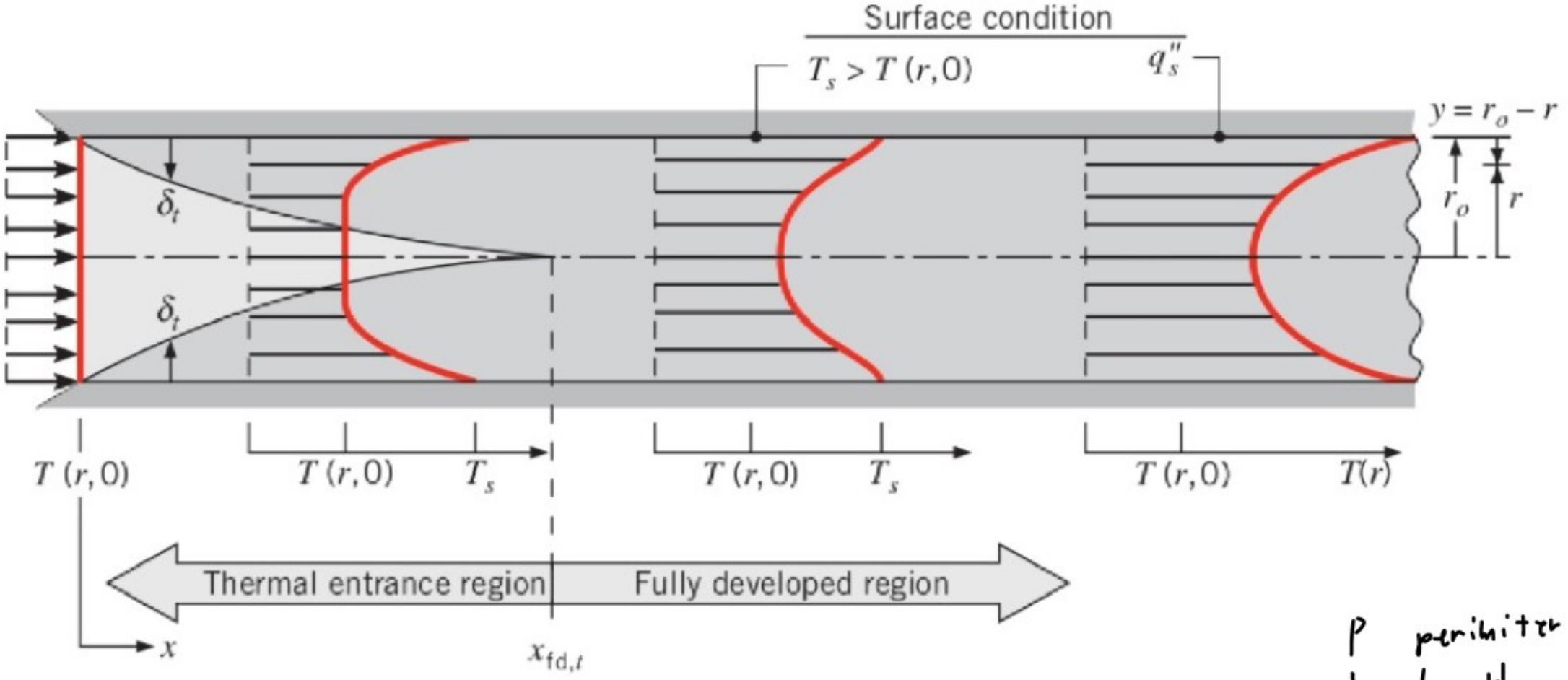
$$\Delta p = p_1 - p_2$$

$$P = \Delta p \, \dot{V}$$

$\dot{V}$ volumetric flow rate

P power

$$\dot{V} = \frac{\dot{m}}{\rho}$$



$\left(\frac{x_{fd,t}}{D}\right)_{lam} = 0.05\, Re_D\, Pr$

$q''_s = h(T_s - T_m)$

$q_{conv} = q''_s\, P L$

P perimeter
L length