Formulário Auxiliar

Constante da lei dos gases perfeitos:

$$R = 0{,}082\,\frac{L.atm}{gmol.K} = 8314\,\frac{kg.m^2}{s^2.kgmol.K}$$

Camada limite laminar

$f(\eta) = 0{,}166\eta^2 - 4{,}594x10^{-4}\eta^5 + ...$ (solução de Blasius)

$\eta = y\sqrt{\frac{\rho v_o}{\mu x}}$ (parâmetro adimensional)

$v_x = v_o f'(\eta)$ (velocidade em x pela solução de Blasius)

$v_y = \frac{1}{2}\sqrt{\frac{\mu v_o}{\rho x}}\left[\eta f'(\eta) - f(\eta)\right]$ (velocidade em y pela solução de Blasius)

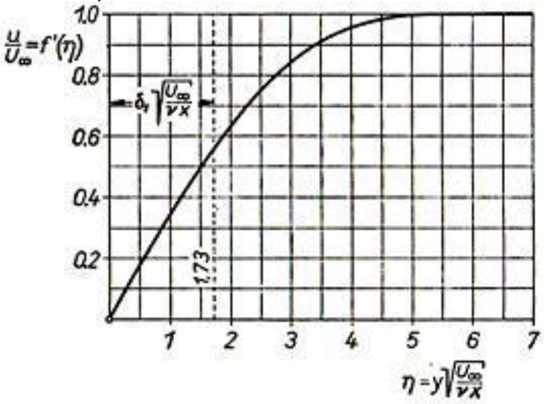
$\delta = 5\sqrt{\frac{\nu x}{U_\infty}} = \frac{5x}{\sqrt{Re_x}}$ (Espessura da camada limite laminar – Blasius)

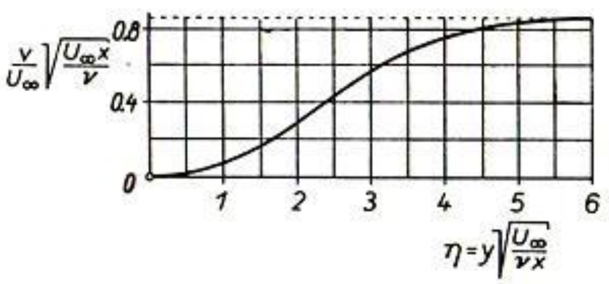
$Re_{cr} = \frac{\rho v_o x_{cr}}{\mu} = 5.10^5$ (valor típico para o número de Reynolds crítico)

$C_D = \frac{0{,}664}{\sqrt{Re_x}}$ (Fator de atrito da camada limite laminar – Blasius)

$C_D = \frac{\tau_W}{\left(\frac{1}{2}\rho U_\infty^2\right)}$ (Fator de atrito da camada limite laminar)

Componentes $u = v_x$ e $v = v_y$ da velocidade na camada limite laminar (placa plana e escoamento laminar)





η	f''	f'	f
0,0	0,332	0,000	0,000
0,1	0,332	0,033	0,002
0,2	0,332	0,066	0,007
0,3	0,332	0,100	0,015
0,4	0,331	0,133	0,027
0,5	0,331	0,166	0,041
0,6	0,330	0,199	0,060
0,8	0,327	0,265	0,106
1,0	0,323	0,330	0,166
1,2	0,317	0,394	0,238
1,4	0,308	0,456	0,323
1,6	0,297	0,517	0,420
1,8	0,283	0,575	0,530
2,0	0,267	0,630	0,650
2,2	0,248	0,681	0,781
2,4	0,228	0,729	0,922
2,4	0,228	0,729	0,922
2,6	0,206	0,772	1,073
2,8	0,184	0,812	1,231
3,0	0,161	0,846	1,397
3,5	0,108	0,913	1,838
4,0	0,064	0,956	2,306
4,5	0,034	0,980	2,790
5,0	0,016	0,992	3,283
5,5	0,007	0,997	3,781
6,0	0,002	0,999	4,280
6,5	0,001	1,000	4,779
7,0	0,000	1,000	5,279
8,0	0,000	1,000	6,279
9,0	0,000	1,000	7,279
10,0	0,000	1,000	8,279

Navier – Stokes

Coordenadas Cartesianas

$$\frac{\partial \rho}{\partial t} + \left(\frac{\partial \rho v_x}{\partial x} + \frac{\partial \rho v_y}{\partial y} + \frac{\partial \rho v_z}{\partial z}\right) = 0$$

$$\rho \frac{\partial v_x}{\partial t} + \rho\left(v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_x}{\partial y} + v_z \frac{\partial v_x}{\partial z}\right) = \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right)$$

$$\rho \frac{\partial v_y}{\partial t} + \rho\left(v_x \frac{\partial v_y}{\partial x} + v_y \frac{\partial v_y}{\partial y} + v_z \frac{\partial v_y}{\partial z}\right) = \rho g_y - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right)$$

$$\rho\frac{\partial v_z}{\partial t}+\rho\left(v_x\frac{\partial v_z}{\partial x}+v_y\frac{\partial v_z}{\partial y}+v_z\frac{\partial v_z}{\partial z}\right)=\rho g_z-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 v_z}{\partial x^2}+\frac{\partial^2 v_z}{\partial y^2}+\frac{\partial^2 v_z}{\partial z^2}\right)$$

$$\tau_{yx}=\tau_{xy}=\mu\left(\frac{\partial v_x}{\partial y}+\frac{\partial v_y}{\partial x}\right)$$

$$\tau_{yz}=\tau_{zy}=\mu\left(\frac{\partial v_z}{\partial y}+\frac{\partial v_y}{\partial z}\right)$$

$$\tau_{zx}=\tau_{xz}=\mu\left(\frac{\partial v_x}{\partial z}+\frac{\partial v_z}{\partial x}\right)$$

$$\tau_{xx}=2\mu\left(\frac{\partial v_x}{\partial x}\right)$$

$$\tau_{yy}=2\mu\left(\frac{\partial v_y}{\partial y}\right)$$

$$\tau_{zz}=2\mu\left(\frac{\partial v_z}{\partial z}\right)$$

Coordenadas Cilíndricas

$$\frac{\partial\rho}{\partial t}+\frac{1}{r}\frac{\partial(\rho r v_r)}{\partial r}+\frac{1}{r}\frac{\partial(\rho v_\theta)}{\partial\theta}+\frac{\partial(\rho v_z)}{\partial z}=0$$

$$\rho\frac{\partial v_\theta}{\partial t}+\rho\left(v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial\theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)$$
$$=\rho g_\theta-\frac{1}{r}\frac{\partial p}{\partial\theta}+\mu\left(\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial(r v_\theta)}{\partial r}+\frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial\theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right)$$

$$\rho\frac{\partial v_r}{\partial t}+\rho\left(v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial\theta}-\frac{v_\theta^2}{r}+v_z\frac{\partial v_r}{\partial z}\right)$$
$$=\rho g_r-\frac{\partial p}{\partial r}+\mu\left(\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial(r v_r)}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial\theta^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial\theta}+\frac{\partial^2 v_r}{\partial z^2}\right)$$

$$\rho\frac{\partial v_z}{\partial t}+\rho\left(v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial\theta}+v_z\frac{\partial v_z}{\partial z}\right)=\rho g_z-\frac{\partial p}{\partial z}+\mu\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial\theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right)$$

$$\tau_{r\theta}=\tau_{\theta r}=\mu\left(r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right)+\frac{1}{r}\frac{\partial v_r}{\partial\theta}\right)$$

$$\tau_{z\theta}=\tau_{\theta z}=\mu\left(\frac{\partial v_\theta}{\partial z}+\frac{1}{r}\frac{\partial v_z}{\partial\theta}\right)$$

$$\tau_{rz}=\tau_{zr}=\mu\left(\frac{\partial v_r}{\partial z}+\frac{\partial v_z}{\partial r}\right)$$

$$rot\vec{V}=\left(\frac{1}{r}\frac{\partial v_z}{\partial\theta}-\frac{\partial v_\theta}{\partial z}\right)\vec{e}_r+\left(\frac{\partial v_r}{\partial z}-\frac{\partial v_z}{\partial r}\right)\vec{e}_\theta+\frac{1}{r}\left(\frac{\partial(r v_\theta)}{\partial r}-\frac{\partial v_r}{\partial\theta}\right)\vec{e}_z$$

Não newtoniano:

$$\tau_{rz}=\eta\dot{\gamma}=k\dot{\gamma}^{n-1}\dot{\gamma}=-k\left(-\frac{dv_z}{dr}\right)^n$$

$$v_z=\left(\frac{n}{n+1}\right)\left[\frac{1}{k}\left(\frac{-\Delta p}{L}\right)\frac{R}{2}\right]^{1/n}R\left\{1-\left(\frac{r}{R}\right)^{\frac{(n+1)}{n}}\right\}$$

$$Q=\pi\left(\frac{n}{3n+1}\right)\left[\frac{1}{2k}\left(\frac{-\Delta p}{L}\right)\right]^{1/n}R^{\frac{(3n+1)}{n}}$$

$$\bar{v}_z = \frac{v_{z,max}}{\frac{3n+1}{n+1}}$$

$$|\tau_{rz}| \leq \tau_0, \dot{\gamma} = \frac{dv_z}{dr} = 0$$

$$|\tau_{rz}| \geq \tau_0, \tau_{rz} = -\tau_0 + \eta \frac{dv_z}{dr}$$

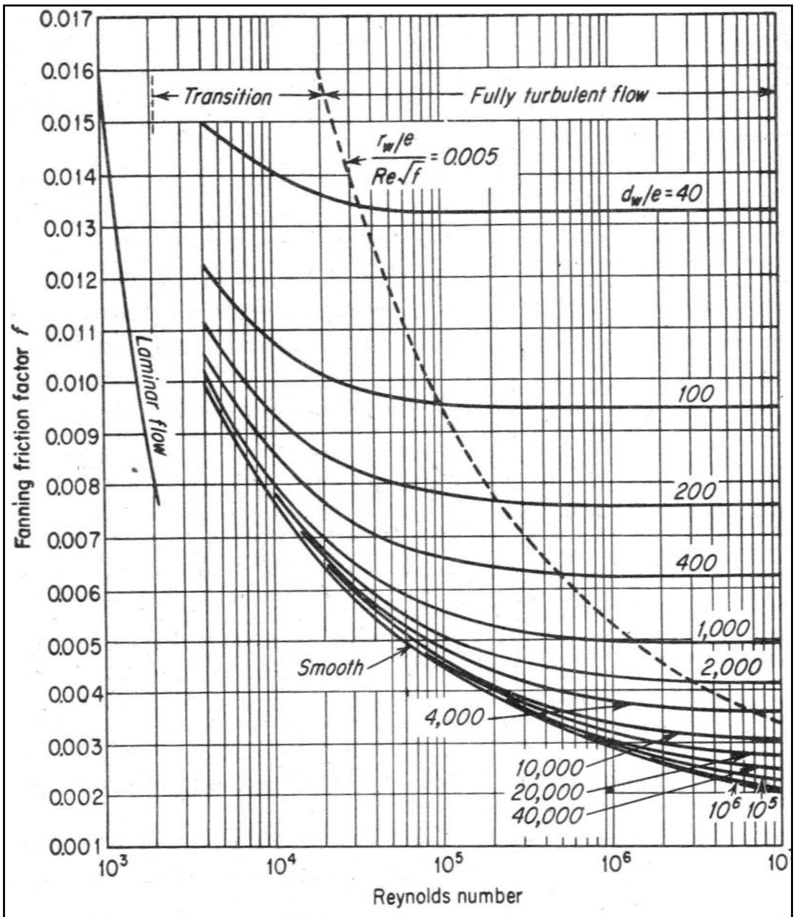


FIG. 7-21. Complete friction-factor plot for both rough and smooth tubes.