7.36 A long, cylindrical, electrical heating element of diameter $D = 12$ mm, thermal conductivity $k = 240$ W/m · K, density $\rho = 2700$ kg/m^3, and specific heat $c_p = 900$ J/kg · K is installed in a duct for which air moves in cross flow over the heater at a temperature and velocity of 30°C and 8 m/s, respectively.

(a) Neglecting radiation, estimate the steady-state surface temperature when, per unit length of the heater, electrical energy is being dissipated at a rate of 1000 W/m.

(b) If the heater is activated from an initial temperature of 30°C, estimate the time required for the surface temperature to come within 10°C of its steady-state value.

$$Re_D = \frac{VD}{\nu} = \frac{8\,\text{m/s}\; 0.012\,\text{m}}{32.39\times10^{-6}\,\text{m}^2/\text{s}} = 2964$$

$T_f = 450$ K

$\nu = 32.39 \times 10^{-6}\ \frac{\text{m}^2}{\text{s}}$

$$\overline{Nu_D} = C Re_D^m Pr^{1/3} = 0.683 (2964)^{0.466} 0.606^{1/3} = 25$$

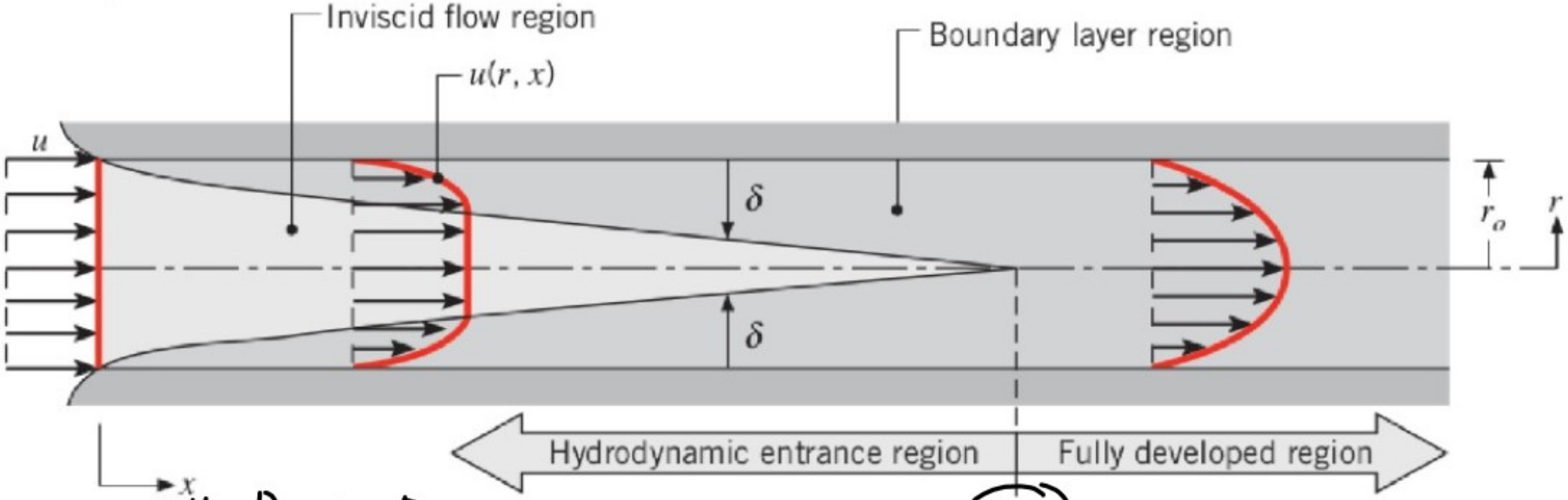
$$\overline{Nu_D} = 0.3 + \frac{0.62 Re_D^{1/2} Pr^{1/3}}{\left(1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right)^{1/4}} \left(1 + \left(\frac{Re_D}{232000}\right)^{5/8}\right)^{4/5} = 27.6$$

$$\overline{Nu_D} = \frac{\bar{h} D}{k} \qquad \bar{h} = \frac{k}{D} \overline{Nu_D} = \frac{0.0373 \frac{W}{mK}}{0.012\ m} 27.6 = 85.7 \frac{W}{m^2 K}$$

$$\frac{T - T_\infty}{\cancel{T_i - T_\infty}} = \frac{b/a}{\cancel{T_i - T_\infty}} = \frac{b}{a} = \frac{\frac{\dot{E}_g}{\cancel{\rho V c}}}{\frac{h A_s}{\cancel{\rho V c}}} = \frac{\dot{E}_g}{h A_s} = \frac{1000\ W/m}{85.7 \frac{W}{m^2 K} \pi\ 0.012\ m}$$

$$\boxed{T = 612\ K}$$

Internal Flow



$Re_D = \frac{\rho u_m D}{\mu} = \frac{u_m D}{\nu}$

u_m mean fluid velocity

$Re_{D_c} = 2300$ Critical Reynolds Number

Laminar

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