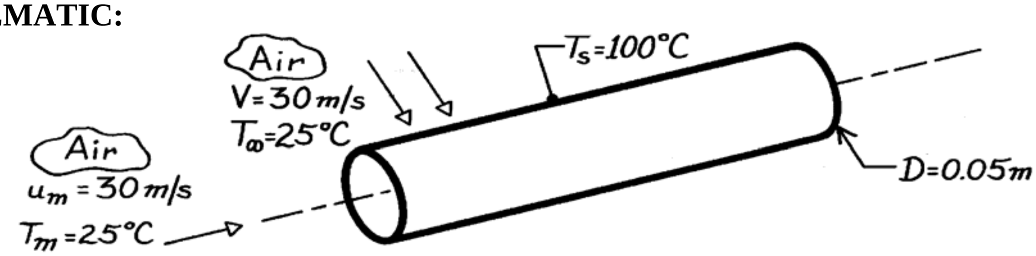
PROBLEM 8.46

KNOWN: Surface temperature and diameter of a tube. Velocity and temperature of air in cross flow. Velocity and temperature of air in fully developed internal flow.

FIND: Convection heat flux associated with the external and internal flows.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Uniform cylinder surface temperature, (3) Fully developed internal flow, (4) For internal flow, air is an ideal gas with negligible viscous dissipation and pressure variations.

PROPERTIES: *Table A-4*, Air (336 K): $\nu = 19.51 \times 10^{-6}$ m^2/s, k = 0.0290 W/m·K, Pr = 0.702.

ANALYSIS: For the *external* and *internal* flows,

$$\mathrm{Re_D} = \frac{\mathrm{VD}}{\nu} = \frac{\mathrm{u_m D}}{\nu} = \frac{30\ \mathrm{m/s} \times 0.05\ \mathrm{m}}{19.71 \times 10^{-6}\mathrm{m^2/s}} = 7.69 \times 10^4.$$

From the Churchill-Bernstein relation for the *external* flow,

$$\overline{\mathrm{Nu}}_\mathrm{D} = 0.3 + \frac{0.62\,\mathrm{Re_D^{1/2}}\,\mathrm{Pr^{1/3}}}{\left[1+(0.4/\mathrm{Pr})^{2/3}\right]^{1/4}}\left[1+\left(\frac{\mathrm{Re_D}}{282{,}000}\right)^{5/8}\right]^{4/5}$$

$$= 0.3 + \frac{0.62(7.69\times10^4)^{1/2}\,0.702^{1/3}}{\left[1+(0.4/0.702)^{2/3}\right]^{1/4}}\left[1+\left(\frac{7.69\times10^4}{282{,}000}\right)^{5/8}\right]^{4/5} = 180$$

Hence, the convection coefficient and heat flux are

$$\overline{\mathrm{h}} = \frac{\mathrm{k}}{\mathrm{D}}\overline{\mathrm{Nu}}_\mathrm{D} = \frac{0.0290\ \mathrm{W/m\cdot K}}{0.05\ \mathrm{m}} \times 180 = 104\ \mathrm{W/m^2\cdot K}$$

$$\mathrm{q''} = \mathrm{h}\left(\mathrm{T_s} - \mathrm{T_\infty}\right) = 104\mathrm{W/m^2\cdot K}\left(100-25\right)^\circ\mathrm{C} = 7840\ \mathrm{W/m^2}.$$ <

Using the Dittus-Boelter correlation, Eq. 8.60, for the *internal* flow, which is turbulent,

$$\overline{\mathrm{Nu}}_\mathrm{D} = 0.023\ \mathrm{Re_D^{4/5}}\ \mathrm{Pr^{0.4}} = 0.023\left(7.69\times10^4\right)^{4/5}\left(0.702\right)^{0.4} = 162$$

$$\overline{\mathrm{h}} = \frac{\mathrm{k}}{\mathrm{D}}\overline{\mathrm{Nu}}_\mathrm{D} = \frac{0.0290\ \mathrm{W/m\cdot K}}{0.05\ \mathrm{m}} \times 162 = 94\ \mathrm{W/m^2\cdot K}$$

Continued…

and the heat flux is

$$q'' = h\left(T_s - T_m\right) = 94\ \mathrm{W/m^2 \cdot K}\left(100 - 25\right)^\circ \mathrm{C} = 7040\ \mathrm{W/m^2}. \qquad <$$

COMMENT: Convection effects associated with the two flow conditions are comparable.