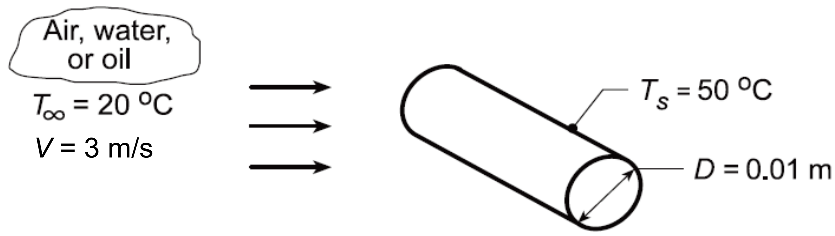
PROBLEM 7.34

KNOWN: Cylinder diameter and surface temperature. Temperature and velocity of fluids in cross flow.

FIND: (a) Rate of heat transfer per unit length for the fluids: atmospheric air and saturated water, and engine oil, for velocity V = 3 m/s, using the Churchill-Bernstein correlation, and (b) Compute and plot q' as a function of the fluid velocity $0.5 \le V \le 10$ m/s.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Uniform cylinder surface temperature.

PROPERTIES: *Table A.4*, Air (T_f = 308 K, 1 atm): $\nu = 16.69 \times 10^{-6}$ m^2/s, k = 0.0269 W/m·K, Pr = 0.706; *Table A.6*, Saturated Water (T_f = 308 K): $\rho = 994$ kg/m^3, $\mu = 725 \times 10^{-6}$ N·s/m^2, k = 0.625 W/m·K, Pr = 4.85; *Table A.5*, Engine Oil (T_f = 308 K): $\nu = 340 \times 10^{-6}$ m^2/s, k = 0.145 W/m·K, Pr = 4000.

ANALYSIS: (a) For each fluid, calculate the Reynolds number and use the Churchill-Bernstein correlation, Eq. 7.54,

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

Fluid: Atmospheric Air

$$Re_D = \frac{VD}{\nu} = \frac{(3\,m/s)\,0.01\,m}{16.69\times10^{-6}\,m^2/s} = 1797$$

$$\overline{Nu}_D = 0.3 + \frac{0.62(1797)^{1/2}(0.706)^{1/3}}{\left[1+(0.4/0.706)^{2/3}\right]^{1/4}}\left[1+\left(\frac{1797}{282,000}\right)^{5/8}\right]^{4/5} = 21.5$$

$$\bar{h} = \frac{k}{D}\overline{Nu}_D = \frac{0.0269\,W/m\cdot K}{0.01\,m}21.5 = 57.9\,W/m^2\cdot K$$

$$q' = \bar{h}\pi D(T_s - T_\infty) = 57.9\,W/m^2\cdot K\,\pi(0.01\,m)(50-20)^\circ C = 54.6\,W/m$$ <

Fluid: Saturated Water

$$Re_D = \frac{VD}{\nu} = \frac{(3\,m/s)\,0.01\,m}{725\times10^{-6}\,N\cdot s/m^2/994\,kg/m^3} = 41,130$$

$$\overline{Nu}_D = 0.3 + \frac{0.62(41,130)^{1/2}(4.85)^{1/3}}{\left[1+(0.4/4.85)^{2/3}\right]^{1/4}}\left[1+\left(\frac{41,130}{282,000}\right)^{5/8}\right]^{4/5} = 252$$

Continued...

$$\bar{h} = \frac{k}{D}\overline{Nu}_D = \frac{0.625\,\mathrm{W/m\cdot K}}{0.01\,\mathrm{m}} 252 = 15{,}730\,\mathrm{W/m^2\cdot K} \qquad q' = 14{,}830\,\mathrm{W/m} \qquad <$$

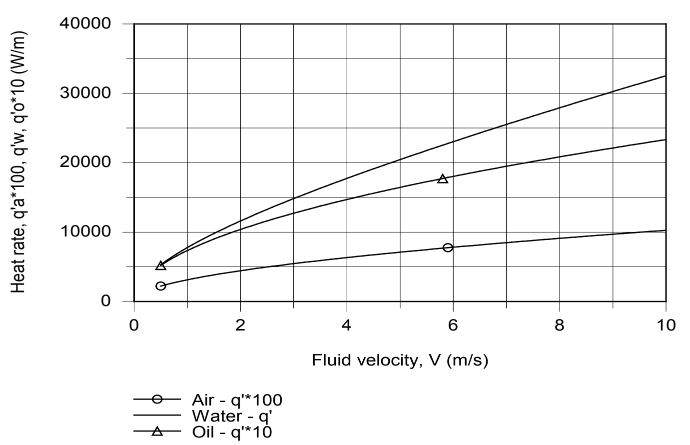
Fluid: Engine Oil

$$\mathrm{Re_D} = \frac{\mathrm{VD}}{\nu} = \frac{(3\,\mathrm{m/s})\,0.01\,\mathrm{m}}{340\times10^{-6}\,\mathrm{m^2/s}} = 88.2$$

$$\overline{\mathrm{Nu}}_\mathrm{D} = 0.3 + \frac{0.62(88.2)^{1/2}(4000)^{1/3}}{\left[1+(0.4/4000)^{2/3}\right]^{1/4}}\left[1+\left(\frac{88.2}{282{,}000}\right)^{5/8}\right]^{4/5} = 93.2$$

$$\bar{\mathrm{h}} = \frac{\mathrm{k}}{\mathrm{D}}\overline{\mathrm{Nu}}_\mathrm{D} = \frac{0.145\,\mathrm{W/m\cdot K}}{0.01\,\mathrm{m}} 93.2 = 1350\,\mathrm{W/m^2\cdot K} \qquad q' = 1270\,\mathrm{W/m} \qquad <$$

(b) Using the *IHT Correlations Tool*, *External Flow*, *Cylinder*, along with the *Properties Tool* for each of the fluids, the heat rates, q', were calculated for the range $0.5 \le V \le 10$ m/s. Note the q' scale multipliers for the air and oil fluids which permit easy comparison of the three curves.



COMMENTS: (1) Note the inapplicability of the Zukauskas relation, Eq. 7.53, since $Pr_{oil} > 500$.

(2) In the plot above, recognize that the heat rate for the water is more than 10 times that with oil and 300 times that with air. How do changes in the velocity affect the heat rates for each of the fluids?