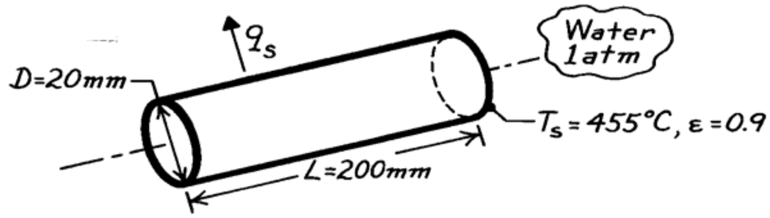
PROBLEM 10.30

KNOWN: Steel bar upon removal from a furnace immersed in water bath.

FIND: Initial heat transfer rate from bar.

SCHEMATIC:



ASSUMPTIONS: (1) Uniform bar surface temperature, (2) Film pool boiling conditions.

PROPERTIES: *Table A-6*, Water, liquid (1 atm, T_{sat} = 100°C): ρ_ℓ = 957.9 kg/m^3, h_{fg} = 2257 kJ/kg; *Table A-4*, Water, vapor ($T_f = (T_s + T_{sat})/2$ = 550K): ρ_v = 0.4005 kg/m^3, $c_{p,v}$ = 1997 J/kg·K, $\nu_v = 47.04 \times 10^{-6}$ m^2/s , k_v = 0.0379 W/m·K.

ANALYSIS: The total heat transfer rate from the bar at the instant of time it is removed from the furnace and immersed in the water is

$$q_s = \bar{h} A_s \left(T_s - T_{sat}\right) = \bar{h} A_s \Delta T_e \qquad (1)$$

where ΔT_e = 455 – 100 = 355K. According to the boiling curve of Figure 10.4, with such a high ΔT_e, film pool boiling will occur. From Eq. 10.9 or 10.10,

$$\bar{h}^{4/3} = \bar{h}_{conv}^{4/3} + \bar{h}_{rad} \cdot \bar{h}^{1/3} \quad \text{or} \quad \bar{h} = \bar{h}_{conv} + \frac{3}{4}\bar{h}_{rad} \; \left(\text{if } h_{conv} > h_{rad}\right). \qquad (2)$$

To estimate the convection coefficient, use Eq. 10.8,

$$\overline{Nu}_D = \frac{\bar{h}_{conv} D}{k_v} = C\left[\frac{g\left(\rho_\ell - \rho_v\right) h'_{fg} D^3}{\nu_v \, k_v \, \Delta T_e}\right]^{1/4} \qquad (3)$$

where C = 0.62 for the horizontal cylinder and $h'_{fg} = h_{fg} + 0.8 \; c_{p,v}\left(T_s - T_{sat}\right)$. Find

$$\bar{h}_{conv} = \frac{0.0379 \text{ W/m}\cdot\text{K}}{0.020 \text{ m}} 0.62 \left[\frac{9.8 \text{ m/s}^2 \left(957.9 - 0.4005\right) \text{kg/m}^3 \left[2257 \times 10^3 + 0.8 \times 1997 \times 355\right] \text{J/kg} \left(0.020\text{m}\right)^3}{\left(47.04 \times 10^{-6}\right) \text{m}^2/\text{s} \times 0.0379 \text{ W/m}\cdot\text{K} \times 355\text{K}}\right]^{1/4}$$

$$\bar{h}_{conv} = 159 \text{ W/m}^2\cdot\text{K}.$$

To estimate the radiation coefficient, use Eq. 10.11,

$$\bar{h}_{rad} = \frac{\varepsilon\sigma\left(T_s^4 - T_{sat}^4\right)}{T_s - T_{sat}} = \frac{0.9 \times 5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4 \left(728^4 - 373^4\right)\text{K}^4}{355\text{K}} = 37.6 \text{ W/m}^2\cdot\text{K}.$$

Substituting numerical values into the simpler form of Eq. (2), find

$$\bar{h} = \left(159 + \left(3/4\right)37.6\right) \text{W/m}^2\cdot\text{K} = 187 \text{ W/m}^2\cdot\text{K}.$$

Using Eq. (1), the heat rate, with $A_s = \pi$ D L, is

$$q_s = 187 \text{ W/m}^2\cdot\text{K}\left(\pi \times 0.020\text{m} \times 0.200\text{m}\right) \times 355\text{K} = 835\text{W}. \qquad <$$

COMMENTS: For these conditions, the combined radiation and convection heat transfer coefficient is 18% larger than the convection coefficient alone.