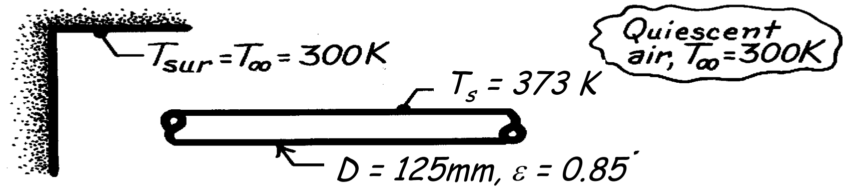
PROBLEM 9.39

KNOWN: Horizontal, uninsulated steam pipe passing through a room.

FIND: Rate of heat loss per unit length from the pipe.

SCHEMATIC:



ASSUMPTIONS: (1) Pipe surface is at uniform temperature, (2) Air is quiescent medium, (3) Surroundings are large compared to pipe.

PROPERTIES: *Table A-4*, Air ($T_f = (T_s + T_\infty)/2 = 337K$, 1 atm): $\nu = 19.61 \times 10^{-6}\ m^2/s$, $k = 0.029\ W/m\cdot K$, $\alpha = 28.0 \times 10^{-6}\ m^2/s$, $Pr = 0.702$, $\beta = 1/T_f = 2.967 \times 10^{-3}\ K^{-1}$.

ANALYSIS: Recognizing that the heat loss from the pipe will be by free convection to the air and by radiation exchange with the surroundings, we can write

$$q' = q'_{conv} + q'_{rad} = \pi D\left[\bar{h}_D\left(T_s - T_\infty\right) + \varepsilon\sigma\left(T_s^4 - T_{sur}^4\right)\right]. \qquad (1)$$

To estimate $\bar{h}_D$, first find Ra_L, Eq. 9.25, and then use the correlation for a horizontal cylinder, Eq. 9.34,

$$Ra_L = \frac{g\beta\left(T_s - T_\infty\right)D^3}{\nu\alpha} = \frac{9.8 m/s^2\left(1/337K\right)\left(373-300\right)K\left(0.125m\right)^3}{19.61\times10^{-6} m^2/s \times 28.0\times10^{-6} m^2/s} = 7.56\times10^6$$

$$\overline{Nu}_D = \left\{0.60 + \frac{0.387\, Ra_L^{1/6}}{\left[1+\left(0.559/Pr\right)^{9/16}\right]^{8/27}}\right\}^2$$

$$\overline{Nu}_D = \left\{0.60 + \frac{0.387\left(7.56\times10^6\right)^{1/6}}{\left[1+\left(0.559/0.702\right)^{9/16}\right]^{8/27}}\right\}^2 = 25.73$$

$$\bar{h}_D = \overline{Nu}_D \cdot k/D = 25.73 \times 0.029\ W/m\cdot K/0.125m = 5.98\ W/m^2\cdot K. \qquad (2)$$

Substituting for $\bar{h}_D$ from Eq. (2) into Eq. (1), find

$$q' = \pi\left(0.125m\right)\left[5.98\ W/m^2\cdot K\left(373-300\right)K + 0.85\times5.67\times10^{-8} W/m^2\cdot K^4\left(373^4 - 300^4\right)K^4\right]$$

$$q' = 171\ W/m + 213\ W/m = 384\ W/m.$$ <

COMMENTS: (1) Note that for this situation, heat transfer by radiation and free convection are of equal importance.

(2) Using Eq. 9.33 with constants C,n from Table 9.2, the estimate for $\bar{h}_D$ is

$$\overline{Nu}_D = CRa_L^n = 0.48\left(7.56\times10^6\right)^{0.250} = 25.17$$

$$\bar{h}_D = \overline{Nu}_D k/D = 25.17\times0.029\ W/m\cdot K/0.125m = 5.85\ W/m^2\cdot K.$$

The agreement is within 3% of the Eq. 9.34 result.