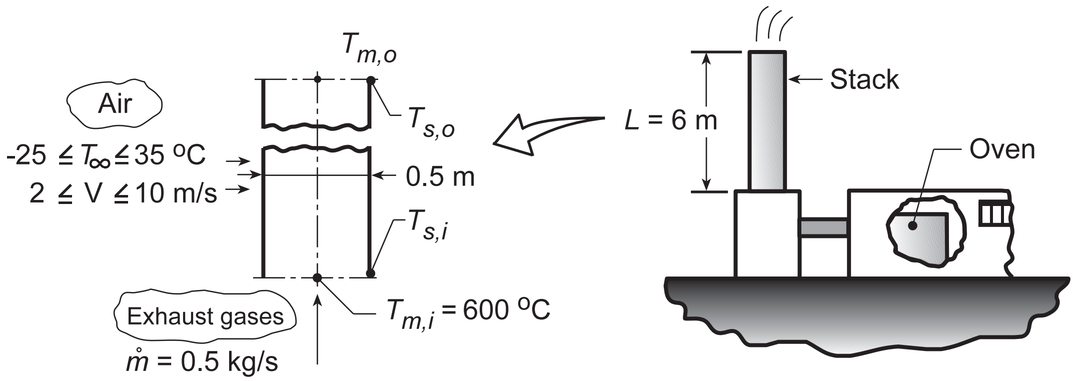
PROBLEM 8.59

KNOWN: Thin-walled, tall stack discharging exhaust gases from an oven into the environment.

FIND: (a) Outlet gas and stack surface temperatures, $T_{m,o}$ and $T_{s,o}$, and (b) Effect of wind temperature and velocity on $T_{m,o}$.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Wall thermal resistance negligible, (3) Exhaust gas properties approximated as those of atmospheric air, (4) Radiative exchange with surroundings negligible, (5) Ideal gas with negligible viscous dissipation and pressure variation, (6) Fully developed flow, (7) Constant properties.

PROPERTIES: *Table A.4*, air (assume $T_{m,o}$ = 773 K, $\overline{T}_m$ = 823 K, 1 atm): c_p = 1104 J/kg·K, μ = 376.4 × 10^{-7} N·s/m^2, k = 0.0584 W/m·K, Pr = 0.712; *Table A.4*, air (assume T_s = 523 K, T_∞ = 4°C = 277 K, T_f = 400 K, 1 atm): ν = 26.41 × 10^{-6} m^2/s, k = 0.0338 W/m·K, Pr = 0.690.

ANALYSIS: (a) From Eq. 8.45a,

$$T_{m,o} = T_\infty - \left(T_\infty - T_{m,i}\right)\exp\left[-\frac{PL}{\dot{m}c_p}\overline{U}\right] \qquad U = 1\Big/\left(\frac{1}{h_i} + \frac{1}{h_o}\right) \qquad (1,2)$$

where h_i and h_o are average coefficients for internal and external flow, respectively.

Internal flow: With a Reynolds number of

$$Re_{D_i} = \frac{4\dot{m}}{\pi D\mu} = \frac{4\times 0.5\,\text{kg/s}}{\pi\times 0.5\,\text{m}\times 376.4\times 10^{-7}\,\text{N}\cdot\text{s/m}^2} = 33,827 \qquad (3)$$

the flow is turbulent. Considering the flow to be fully developed throughout the stack (L/D = 12) and with $T_s < T_m$, the Dittus-Boelter correlation has the form

$$Nu_D = \frac{h_i D}{k} = 0.023\,Re_{D_i}^{4/5}\,Pr^{0.3} \qquad (4)$$

$$h_i = \frac{58.4\times 10^{-3}\,\text{W/m}\cdot\text{K}}{0.5\,\text{m}}\times 0.023(33,827)^{4/5}(0.712)^{0.3} = 10.2\,\text{W/m}^2\cdot\text{K}.$$

External flow: Working with the Churchill/Bernstein correlation, the Reynolds and Nusselt numbers are

$$Re_{D_o} = \frac{VD}{\nu} = \frac{5\,\text{m/s}\times 0.5\,\text{m}}{26.41\times 10^{-6}\,\text{m}^2/\text{s}} = 94,660 \qquad (5)$$

Continued...

PROBLEM 8.59 (Cont.)

$$\overline{Nu}_D = 0.3 + \frac{0.62\,Re_D^{1/2}\,Pr^{1/3}}{\left[1+\left(0.4/Pr\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re_D}{282,000}\right)^{5/8}\right]^{4/5} = 205$$

Hence,

$$h_o = \left(0.0338\,W/m\cdot K/0.5\,m\right)\times 205 = 13.9\,W/m^2\cdot K \qquad (6)$$

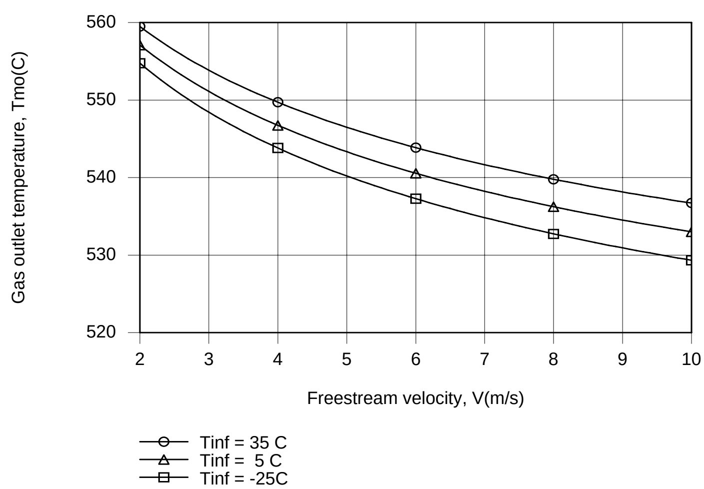
The outlet gas temperature is then

$$T_{m,o} = 4^\circ C - \left(4-600\right)^\circ C\exp\left[-\frac{\pi\times 0.5\,m\times 6\,m}{0.5\,kg/s\times 1104\,J/kg\cdot K}\left(\frac{1}{1/10.2+1/13.9}W/m^2\cdot K\right)\right] = 543^\circ C \qquad <$$

The outlet stack surface temperature can be determined from a local surface energy balance of the form, $h_i(T_{m,o} - T_{s,o}) = h_o(T_{s,o} - T_\infty)$, which yields

$$T_{s,o} = \frac{h_i T_{m,o} + h_o T_\infty}{h_i + h_o} = \frac{\left(10.2\times 543 + 13.9\times 4\right)W/m^2}{\left(10.2+13.9\right)W/m^2\cdot K} = 232^\circ C \qquad <$$

(b) Using the Correlations and Properties Toolpads of IHT, with a surface temperature of T_s = 523 K assumed solely for the purpose of evaluating properties associated with airflow over the cylinder, the following results were generated.



Due to the elevated temperatures of the gas, the variation in ambient temperature has only a small effect on the gas exit temperature. However, the effect of the freestream velocity is more pronounced. Discharge temperatures of approximately 530 and 560°C would be representative of cold/windy and warm/still atmospheric conditions, respectively.

COMMENTS: If there are constituents in the discharge gas flow that condense or precipitate out at temperatures below $T_{s,o}$, this operating condition should be avoided.