Problem 14-17
Gases from an incinerator are released to the atmosphere using a stack that is 0.6 m in diameter and 10 m high. The outer surface of the stack is at 40°C and the surrounding air is at 10°C. Determine the rate of heat transfer from the stack assuming a) no wind, and b) a wind at 20 km/hr.

**Properties** The properties of air at 1 atm and the film temperature of \((T_s + T_\infty)/2 = (40+10)/2 = 25°C\) are (Table A-22)

\[
\begin{align*}
  k &= 0.02551 \text{ W/m·°C} \\
  \nu &= 1.562 \times 10^{-5} \text{ m}^2/\text{s} \\
  Pr &= 0.7296 \\
  \beta &= \frac{1}{T_f} = \frac{1}{(25+273)K} = 0.003356 \text{ K}^{-1}
\end{align*}
\]

**Analysis (a)** When there is no wind heat transfer is by natural convection. The characteristic length in this case is the height of the stack, \(L_c = L = 10\) m. Then,

\[
Ra = \frac{g \beta (T_s - T_\infty) L^3}{\nu^2 Pr} = \frac{(9.81 \text{ m/s}^2)(0.003356 \text{ K}^{-1})(40-10 \text{ K})(10 \text{ m})^3}{(1.562 \times 10^{-5} \text{ m}^2/\text{s})^2}(0.7296) = 2.953 \times 10^{12}
\]

We can treat this vertical cylinder as a vertical plate since

\[
\frac{35L}{Gr^{1/4}} = \frac{35(10)}{(2.953 \times 10^{12} / 0.7296)^{1/4}} = 0.246 < 0.6 \quad \text{and thus } D \geq \frac{35L}{Gr^{1/4}}
\]

The Nusselt number is determined from

\[
Nu = 0.1Ra^{1/3} = 0.1(2.953 \times 10^{12})^{1/3} = 1435
\]

Then

\[
h = \frac{k}{L_c} Nu = \frac{0.02551 \text{ W/m·°C}}{10 \text{ m}} (1435) = 3.660 \text{ W/m}^2\cdot\text{°C}
\]

and

\[
\dot{Q} = hA(T_s - T_\infty) = (3.660 \text{ W/m}^2\cdot\text{°C}) (\pi \times 0.6 \times 10 \text{ m}^2)(40 - 10)\text{°C} = 2070 \text{ W}
\]
Problem 14-17 (Continued)

Gases from an incinerator are released to the atmosphere using a stack that is 0.6 m in diameter and 10 m high. The outer surface of the stack is at 40°C and the surrounding air is at 10°C. Determine the rate of heat transfer from the stack assuming a) no wind, and b) a wind at 20 km/hr.

(b) When the stack is exposed to 20 km/h winds

\[ \text{Re} = \frac{VD}{\nu} = \frac{(20 \times 1000 / 3600 \text{ m/s})(0.6 \text{ m})}{1.562 \times 10^{-5} \text{ m}^2/\text{s}} = 213,400 \]

\[ \text{Nu} = 0.027 \text{Re}^{0.805} \text{Pr}^{1/3} = 0.027(213,400)^{0.805}(0.7296)^{1/3} = 473.9 \]

\[ h = \frac{k}{D} \text{Nu} = \frac{0.02551 \text{ W/m.}^\circ \text{C}}{0.6 \text{ m}} (473.9) = 20.15 \text{ W/m}^2.\circ \text{C} \]

\[ \dot{Q} = hA(T_s - T_\infty) = (20.15 \text{ W/m}^2.\circ \text{C})(\pi \times 0.6 \times 10 \text{ m}^2)(40 - 10)^\circ \text{C} = 11,390 \text{ W} \]

There is more than five-fold increase in heat transfer due to winds.
Problem 14-19

A 10-m-long section of a 6-cm-diameter horizontal hot-water pipe passes through a large room whose temperature is 27°C. If the temperature and the emissivity of the pipe are 73°C and 0.8, determine the rate of heat loss from the pipe by a) natural convection and b) radiation.

Properties
The properties of air at 1 atm and the film temperature of \((T_s + T_\infty)/2 = (73 + 27)/2 = 50°C\) are (Table A-22)

\[
k = 0.02735 \text{ W/m.}°\text{C}
\]
\[
\nu = 1.798 \times 10^{-5} \text{ m}^2/\text{s}
\]
\[
Pr = 0.7228
\]
\[
\beta = \frac{1}{T_f} = \frac{1}{(50 + 273)K} = 0.003096 \text{ K}^{-1}
\]

The characteristic length \(L_c = D = 0.06 \text{ m}\).

\[
Ra = \frac{g \beta (T_s - T_\infty) D^3}{\nu^2 \Pr}
\]
\[
= \frac{(9.81 \text{ m/s}^2)(0.003096 \text{ K}^{-1})(73 - 27 \text{ K})(0.06 \text{ m})^3}{(1.798 \times 10^{-5} \text{ m}^2/\text{s})^2 (0.7228)} = 6.747 \times 10^5
\]

(From Eq. 14-25, Page 619)

\[
Nu = \left\{ 0.6 + \frac{0.387Ra^{1/6}}{1 + (0.559/Pr)^{9/16}} \right\}^{2/3} = \left\{ 0.6 + \frac{0.387(6.747 \times 10^5)^{1/6}}{1 + (0.559/0.7228)^{9/16}} \right\}^{2/3} = 13.05
\]

\[
h = \frac{k}{D} Nu = \frac{0.02735 \text{ W/m.}°\text{C}}{0.06 \text{ m}} (13.05) = 5.950 \text{ W/m}^2.°\text{C}
\]

\[
A_s = \pi DL = \pi (0.06 \text{ m})(10 \text{ m}) = 1.885 \text{ m}^2
\]

\[
\dot{Q} = hA_s(T_s - T_\infty) = (5.950 \text{ W/m}^2.°\text{C})(1.885 \text{ m}^2)(73 - 27)°\text{C} = 516 \text{ W}
\]

(b) The radiation heat loss from the pipe is

\[
\dot{Q}_{rad} = \varepsilon A_s \sigma (T_s^4 - T_{surr}^4)
\]
\[
= (0.8)(1.885 \text{ m}^2)(5.67 \times 10^{-8} \text{ W/m}^2.\text{K}^4)[(73 + 273 \text{ K})^4 - (27 + 273 \text{ K})^4] = 533 \text{ W}
\]