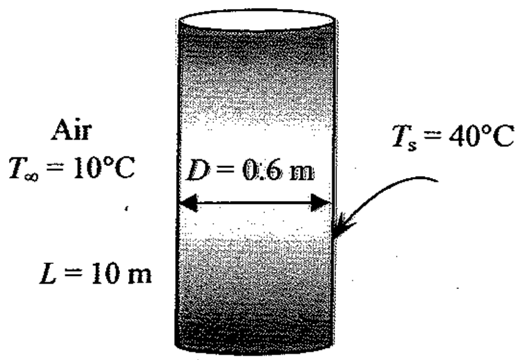
Problem 14-17

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)

$$k = 0.02551 \text{ W/m.°C}$$

$$\nu = 1.562\times10^{-5} \text{ m}^2\text{/s}$$

$$\text{Pr} = 0.7296$$

$$\beta = \frac{1}{T_f} = \frac{1}{(25+273)\text{K}} = 0.003356 \text{ K}^{-1}$$

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,

$$Ra = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}\text{Pr}$$

$$= \frac{(9.81 \text{ m/s}^2)(0.003356 \text{ K}^{-1})(40-10 \text{ K})(10 \text{ m})^3}{(1.562\times10^{-5} \text{ m}^2\text{/s})^2}(0.7296) = 2.953\times10^{12}$$

We can treat this vertical cylinder as a vertical plate since

$$\frac{35L}{Gr^{1/4}} = \frac{35(10)}{(2.953\times10^{12}/0.7296)^{1/4}} = 0.246 < 0.6 \quad \text{and thus } D \ge \frac{35L}{Gr^{1/4}}$$

The Nusselt number is determined from

$$Nu = 0.1Ra^{1/3} = 0.1(2.953\times10^{12})^{1/3} = 1435$$

Then

$$h = \frac{k}{L_c}Nu = \frac{0.02551 \text{ W/m.°C}}{10 \text{ m}}(1435) = 3.660 \text{ W/m}^2\text{.°C}$$

and

$$\dot{Q} = hA(T_s - T_\infty) = (3.660 \text{ W/m}^2\text{.°C})(\pi\times0.6\times10 \text{ m}^2)(40-10)\text{°C} = \mathbf{2070 \text{ W}}$$

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

$$\mathrm{Re} = \frac{VD}{\nu} = \frac{(20\times1000/3600\ \mathrm{m/s})(0.6\ \mathrm{m})}{1.562\times10^{-5}\ \mathrm{m^2/s}} = 213{,}400$$

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

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

$$\dot{Q} = hA(T_s - T_\infty) = (20.15\ \mathrm{W/m^2.^\circ C})(\pi\times0.6\times10\ \mathrm{m^2})(40-10)^\circ\mathrm{C} = \mathbf{11{,}390\ W}$$

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.

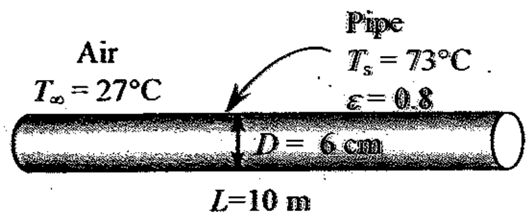
Properties The properties of air at 1 atm and the film temperature of $(T_s+T_\infty)/2 = (73+27)/2 = 50°C$ are (Table A-22)

$$k = 0.02735 \text{ W/m.°C}$$

$$\nu = 1.798\times10^{-5} \text{ m}^2/\text{s}$$

$$\Pr = 0.7228$$

$$\beta = \frac{1}{T_f} = \frac{1}{(50+273)\text{K}} = 0.003096 \text{ K}^{-1}$$



The characteristic length $L_c = D = 0.06$ m.

$$Ra = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2}\Pr$$

$$= \frac{(9.81 \text{ m/s}^2)(0.003096 \text{ K}^{-1})(73-27 \text{ K})(0.06 \text{ m})^3}{(1.798\times10^{-5} \text{ m}^2/\text{s})^2}(0.7228) = 6.747\times10^5$$

(From Eq. 14-25, Page 619)

$$Nu = \left\{0.6 + \frac{0.387Ra^{1/6}}{\left[1+(0.559/\Pr)^{9/16}\right]^{8/27}}\right\}^2 = \left\{0.6 + \frac{0.387(6.747\times10^5)^{1/6}}{\left[1+(0.559/0.7228)^{9/16}\right]^{8/27}}\right\}^2 = 13.05$$

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

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

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

(*b*) The radiation heat loss from the pipe is

$$\dot{Q}_{rad} = \varepsilon A_s\sigma(T_s^{\ 4} - T_{surr}^{\ 4})$$

$$= (0.8)(1.885 \text{ m}^2)(5.67\times10^{-8} \text{ W/m}^2\text{.K}^4)\left[(73+273 \text{ K})^4 - (27+273 \text{ K})^4\right] = \mathbf{533 \text{ W}}$$