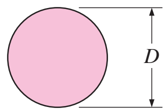
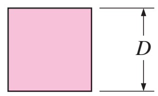
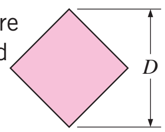
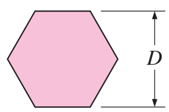
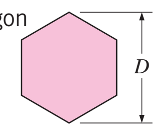
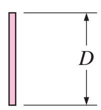
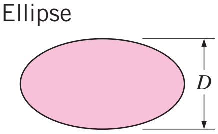
TABLE 7-1

Empirical correlations for the average Nusselt number for forced convection over circular and noncircular cylinders in cross flow (from Zukauskas, Ref. 14, and Jakob, Ref. 6)

Cross-section of the cylinder	Fluid	Range of Re	Nusselt number
Circle 	Gas or liquid	0.4–4 4–40 40–4000 4000–40,000 40,000–400,000	$\text{Nu} = 0.989\text{Re}^{0.330}\,\text{Pr}^{1/3}$ $\text{Nu} = 0.911\text{Re}^{0.385}\,\text{Pr}^{1/3}$ $\text{Nu} = 0.683\text{Re}^{0.466}\,\text{Pr}^{1/3}$ $\text{Nu} = 0.193\text{Re}^{0.618}\,\text{Pr}^{1/3}$ $\text{Nu} = 0.027\text{Re}^{0.805}\,\text{Pr}^{1/3}$
Square 	Gas	5000–100,000	$\text{Nu} = 0.102\text{Re}^{0.675}\,\text{Pr}^{1/3}$
Square (tilted 45°) 	Gas	5000–100,000	$\text{Nu} = 0.246\text{Re}^{0.588}\,\text{Pr}^{1/3}$
Hexagon 	Gas	5000–100,000	$\text{Nu} = 0.153\text{Re}^{0.638}\,\text{Pr}^{1/3}$
Hexagon (tilted 45°) 	Gas	5000–19,500 19,500–100,000	$\text{Nu} = 0.160\text{Re}^{0.638}\,\text{Pr}^{1/3}$ $\text{Nu} = 0.0385\text{Re}^{0.782}\,\text{Pr}^{1/3}$
Vertical plate 	Gas	4000–15,000	$\text{Nu} = 0.228\text{Re}^{0.731}\,\text{Pr}^{1/3}$
Ellipse 	Gas	2500–15,000	$\text{Nu} = 0.248\text{Re}^{0.612}\,\text{Pr}^{1/3}$

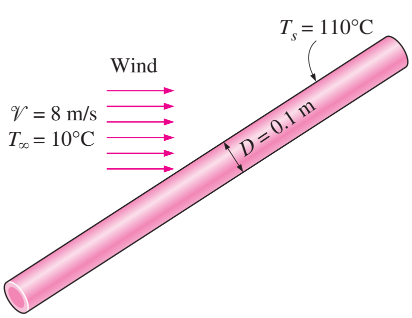


FIGURE 7–23
Schematic for Example 7–5.

EXAMPLE 7–5 Heat Loss from a Steam Pipe in Windy Air

A long 10-cm-diameter steam pipe whose external surface temperature is 110°C passes through some open area that is not protected against the winds (Fig. 7–23). Determine the rate of heat loss from the pipe per unit of its length when the air is at 1 atm pressure and 10°C and the wind is blowing across the pipe at a velocity of 8 m/s.

SOLUTION A steam pipe is exposed to windy air. The rate of heat loss from the steam is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Radiation effects are negligible. **3** Air is an ideal gas.

Properties The properties of air at the average film temperature of $T_f = (T_s + T_\infty)/2 = (110 + 10)/2 = 60°C$ and 1 atm pressure are (Table A-15)

$$k = 0.02808 \text{ W/m}\cdot°\text{C} \qquad \text{Pr} = 0.7202$$
$$\nu = 1.896 \times 10^{-5} \text{ m}^2/\text{s}$$

Analysis The Reynolds number is

$$\text{Re} = \frac{\mathcal{V}D}{\nu} = \frac{(8 \text{ m/s})(0.1 \text{ m})}{1.896 \times 10^{-5} \text{ m}^2/\text{s}} = 4.219 \times 10^4$$

The Nusselt number can be determined from

$$\begin{aligned}\text{Nu} = \frac{hD}{k} &= 0.3 + \frac{0.62\,\text{Re}^{1/2}\,\text{Pr}^{1/3}}{[1 + (0.4/\text{Pr})^{2/3}]^{1/4}}\left[1 + \left(\frac{\text{Re}}{282{,}000}\right)^{5/8}\right]^{4/5} \\ &= 0.3 + \frac{0.62(4.219 \times 10^4)^{1/2}\,(0.7202)^{1/3}}{[1 + (0.4/0.7202)^{2/3}]^{1/4}}\left[1 + \left(\frac{4.219 \times 10^4}{282{,}000}\right)^{5/8}\right]^{4/5} \\ &= 124\end{aligned}$$

and

$$h = \frac{k}{D}\text{Nu} = \frac{0.02808 \text{ W/m}\cdot°\text{C}}{0.1 \text{ m}}(124) = 34.8 \text{ W/m}^2\cdot°\text{C}$$

Then the rate of heat transfer from the pipe per unit of its length becomes

$$A_s = pL = \pi DL = \pi(0.1 \text{ m})(1 \text{ m}) = 0.314 \text{ m}^2$$
$$\dot{Q} = hA_s(T_s - T_\infty) = (34.8 \text{ W/m}^2\cdot\text{C})(0.314 \text{ m}^2)(110 - 10)°\text{C} = \mathbf{1093 \text{ W}}$$

The rate of heat loss from the entire pipe can be obtained by multiplying the value above by the length of the pipe in m.

Discussion The simpler Nusselt number relation in Table 7–1 in this case would give Nu = 128, which is 3 percent higher than the value obtained above using Eq. 7-35.

EXAMPLE 7–6 Cooling of a Steel Ball by Forced Air

A 25-cm-diameter stainless steel ball (ρ = 8055 kg/m^3, C_p = 480 J/kg · °C) is removed from the oven at a uniform temperature of 300°C (Fig. 7–24). The ball is then subjected to the flow of air at 1 atm pressure and 25°C with a velocity of 3 m/s. The surface temperature of the ball eventually drops to 200°C. Determine the average convection heat transfer coefficient during this cooling process and estimate how long the process will take.

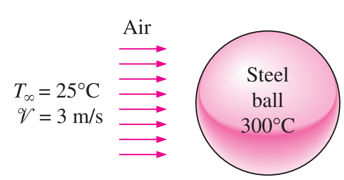


FIGURE 7–24
Schematic for Example 7–6.