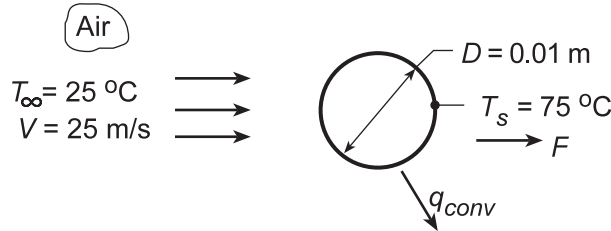


PROBLEM 7.74

KNOWN: Temperature and velocity of air flow over a sphere of prescribed surface temperature and diameter.

FIND: (a) Drag force, (b) Heat transfer rate with air velocity of 25 m/s; and (c) Compute and plot the heat rate as a function of air velocity for the range $1 \leq V \leq 25$ m/s.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Uniform surface temperature, (3) Negligible radiation exchange with surroundings.

PROPERTIES: Table A.4, Air ($T_\infty = 298$ K, 1 atm): $\mu = 184 \times 10^{-7}$ N·s/m²; $\nu = 15.71 \times 10^{-6}$ m²/s, $k = 0.0261$ W/m·K, $Pr = 0.71$; ($T_s = 348$ K): $\mu = 208 \times 10^{-7}$ N·s/m²; ($T_f = 323$ K): $\nu = 18.2 \times 10^{-6}$ m²/s, $\rho = 1.085$ kg/m³.

ANALYSIS: (a) Working with properties evaluated at T_f

$$Re_D = \frac{VD}{\nu} = \frac{25 \text{ m/s}(0.01 \text{ m})}{18.2 \times 10^{-6} \text{ m}^2/\text{s}} = 1.37 \times 10^4$$

and from Fig. 7.9, find $C_D \approx 0.4$. Hence

$$F_D = C_D \left(\pi D^2 / 4 \right) \left(\rho V^2 / 2 \right) = 0.4 (\pi / 4) (0.01 \text{ m})^2 1.085 \text{ kg/m}^3 (25 \text{ m/s})^2 / 2 = 0.011 \text{ N} <$$

(b) With

$$Re_D = \frac{VD}{\nu} = \frac{25 \text{ m/s}(0.01 \text{ m})}{15.71 \times 10^{-6} \text{ m}^2/\text{s}} = 1.59 \times 10^4$$

it follows from the Whitaker relation that

$$\begin{aligned} \overline{Nu}_D &= 2 + \left[0.4 Re_D^{1/2} + 0.06 Re_D^{2/3} \right] Pr^{0.4} \left(\frac{\mu}{\mu_s} \right)^{1/4} \\ \overline{Nu}_D &= 2 + \left[0.4 (1.59 \times 10^4)^{1/2} + 0.06 (1.59 \times 10^4)^{2/3} \right] (0.71)^{0.4} \left(\frac{184}{208} \right)^{1/4} = 76.7 \end{aligned}$$

Hence, the convection coefficient and convection heat rate are

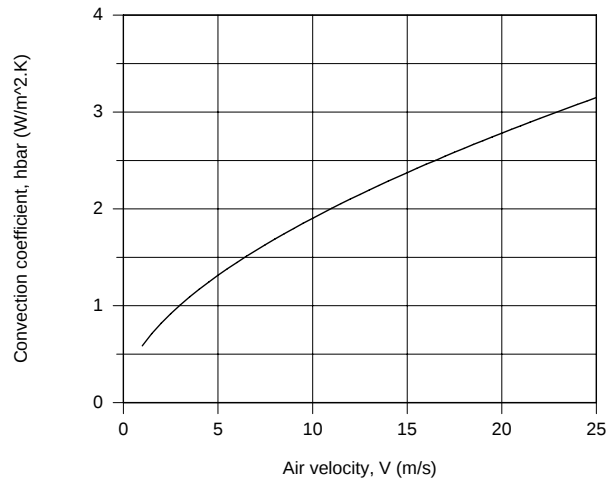
$$\bar{h} = \overline{Nu}_D \frac{k}{D} = 76.7 \frac{0.0261 \text{ W/m} \cdot \text{K}}{0.01 \text{ m}} = 200 \text{ W/m}^2 \cdot \text{K}$$

$$q = \bar{h} \pi D^2 (T_s - T_\infty) = 200 \text{ W/m}^2 \cdot \text{K} \times \pi (0.01 \text{ m})^2 (75 - 25)^\circ \text{C} = 3.14 \text{ W} <$$

Continued...

PROBLEM 7.74 (Cont.)

(c) Using the *IHT Correlation Tool, External Flow, Sphere*, the average coefficient and heat rate were calculated and are plotted below.



COMMENTS: (1) A copy of the IHT Workspace used to generate the above plot is shown below.

// Correlation Tool - External Flow, Sphere:

NuDbar = NuL_bar_EF_SP(ReD, Pr, mu, mus) // Eq 7.56

NuDbar = $\bar{h} \cdot D / k$

ReD = $V \cdot D / \nu$

/* Evaluate properties at Tinf and the surface temperature, Ts. */

/* Correlation description: External flow (EF) over a sphere (SP), average coefficient, $3.5 < \text{ReD} < 7.6 \times 10^4$, $0.71 < \text{Pr} < 380$, $1.0 < (\mu/\mu_s) < 3.2$, Whitaker correlation, Eq 7.56. See Table 7.7. */

// Properties Tool - Air:

// Air property functions : From Table A.4

// Units: T(K); 1 atm pressure

mu = mu_T("Air", Tinf)

// Viscosity, N·s/m²

mus = mu_T("Air", Ts)

// Viscosity, N·s/m²

nu = nu_T("Air", Tinf)

// Kinematic viscosity, m²/s

k = k_T("Air", Tinf)

// Thermal conductivity, W/m·K

Pr = Pr_T("Air", Tinf)

// Prandtl number

// Heat Rate Equation:

q = $\bar{h} \cdot \pi \cdot D^2 \cdot (T_s - T_{\text{inf}})$

// Assigned Variables:

D = 0.01

// Sphere diameter, m

Ts = 75 + 273

// Surface temperature, K

V = 25

// Airstream velocity, m/s

Tinf = 25 + 273

// Airstream temperature, K