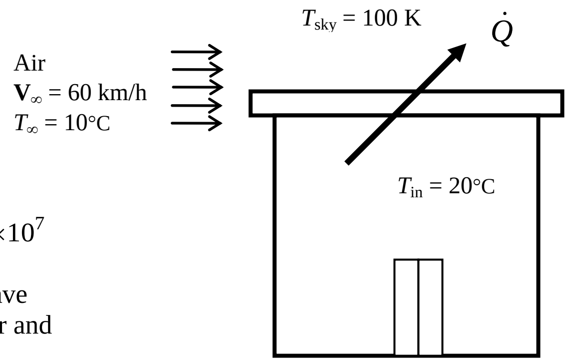
**7-99** Wind is blowing over the roof of a house. The rate of heat transfer through the roof and the cost of this heat loss for 14-h period are to be determined.

***Assumptions*** **1** Steady operating conditions exist. **2** The critical Reynolds number is $Re_{cr} = 5\times10^5$. **3** Air is an ideal gas with constant properties. **4** The pressure of air is 1 atm.

***Properties*** Assuming a film temperature of 10°C, the properties of air are (Table A-15)




$$k = 0.02439\ \text{W/m.°C}$$
$$\upsilon = 1.426\times10^{-5}\ \text{m}^2\text{/s}$$
$$\Pr = 0.7336$$

***Analysis*** The Reynolds number is

$$\text{Re}_L = \frac{V_\infty L}{\upsilon} = \frac{[(60\times1000/3600)\ \text{m/s}](20\ \text{m})}{1.426\times10^{-5}\ \text{m}^2\text{/s}} = 2.338\times10^7$$

which is greater than the critical Reynolds number. Thus we have combined laminar and turbulent flow. Then the Nusselt number and the heat transfer coefficient are determined to be

$$Nu = \frac{hL}{k} = (0.037\text{Re}_L^{\ 0.8} - 871)\Pr^{1/3} = [0.037(2.338\times10^7)^{0.8} - 871](0.7336)^{1/3} = 2.542\times10^4$$

$$h = \frac{k}{L}Nu = \frac{0.02439\ \text{W/m.°C}}{20\ \text{m}}(2.542\times10^4) = 31.0\ \text{W/m}^2\text{.°C}$$

In steady operation, heat transfer from the room to the roof (by convection and radiation) must be equal to the heat transfer from the roof to the surroundings (by convection and radiation), which must be equal to the heat transfer through the roof by conduction. That is,

$$\dot{Q} = \dot{Q}_{\text{room to roof, conv+rad}} = \dot{Q}_{\text{roof, cond}} = \dot{Q}_{\text{roof to surroundings, conv+rad}}$$

Taking the inner and outer surface temperatures of the roof to be $T_{s,in}$ and $T_{s,out}$, respectively, the quantities above can be expressed as

$$\dot{Q}_{\text{room to roof,conv+rad}} = h_i A_s (T_{room} - T_{s,in}) + \varepsilon A_s \sigma (T_{room}^{\ 4} - T_{s,in}^{\ 4}) = (5\ \text{W/m}^2\text{.°C})(300\ \text{m}^2)(20 - T_{s,in})\text{°C}$$
$$+ (0.9)(300\ \text{m}^2)(5.67\times10^{-8}\ \text{W/m}^2\text{.K}^4)\left[(20+273\text{K})^4 - (T_{s,in}+273\text{K})^4\right]$$

$$\dot{Q}_{\text{roof,cond}} = kA_s\frac{T_{s,in}-T_{s,out}}{L} = (2\ \text{W/m.°C})(300\ \text{m}^2)\frac{T_{s,in}-T_{s,out}}{0.15\ \text{m}}$$

$$\dot{Q}_{\text{roof to surr,conv+rad}} = h_o A_s (T_{s,out} - T_{surr}) + \varepsilon A_s \sigma (T_{s,out}^{\ 4} - T_{surr}^{\ 4}) = (31.0\ \text{W/m}^2\text{.°C})(300\ \text{m}^2)(T_{s,out} - 10)\text{°C}$$
$$+ (0.9)(300\ \text{m}^2)(5.67\times10^{-8}\ \text{W/m}^2\text{.K}^4)\left[(T_{s,out}+273\text{K})^4 - (100\ \text{K})^4\right]$$

Solving the equations above simultaneously gives

$$\dot{Q} = 28{,}025\ \text{W} = \mathbf{28.03\ kW}, \qquad T_{s,in} = 10.6\text{°C, and } T_{s,out} = 3.5\text{°C}$$

The total amount of natural gas consumption during a 14-hour period is

$$Q_{gas} = \frac{Q_{total}}{0.85} = \frac{\dot{Q}\Delta t}{0.85} = \frac{(28.03\ \text{kJ/s})(14\times3600\text{s})}{0.85}\left(\frac{1\ \text{therm}}{105{,}500\text{kJ}}\right) = 15.75\ \text{therms}$$

Finally, the money lost through the roof during that period is

$$\text{Money lost} = (15.75\ \text{therms})(\$0.60/\text{therm}) = \mathbf{\$9.45}$$

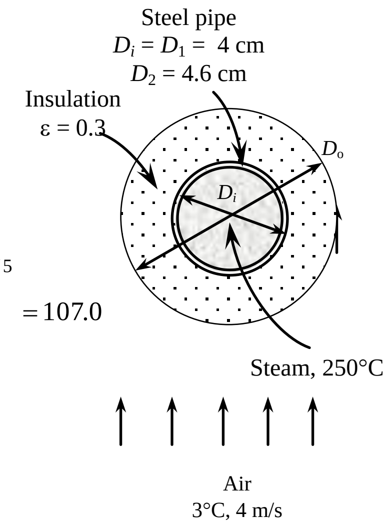
**7-100** Steam is flowing in a stainless steel pipe while air is flowing across the pipe. The rate of heat loss from the steam per unit length of the pipe is to be determined.

***Assumptions*** **1** Steady operating conditions exist. **2** Air is an ideal gas with constant properties. **3** The pressure of air is 1 atm.

***Properties*** Assuming a film temperature of 10°C, the properties of air are (Table A-15)

$$k = 0.02439\ \text{W/m.°C}, \qquad \upsilon = 1.426\times10^{-5}\ \text{m}^2\text{/s}, \qquad \text{and} \qquad \Pr = 0.7336$$

***Analysis*** The outer diameter of insulated pipe is $D_o$ = 4.6+2×3.5=11.6 cm = 0.116 m. The Reynolds number is




$$\text{Re} = \frac{\mathbf{V}_\infty D_o}{\upsilon} = \frac{(4\ \text{m/s})(0.116\text{m})}{1.426\times10^{-5}\ \text{m}^2\text{/s}} = 3.254\times10^4$$

The Nusselt number for flow across a cylinder is determined from

$$Nu = \frac{hD_o}{k} = 0.3 + \frac{0.62\,\text{Re}^{0.5}\,\Pr^{1/3}}{\left[1+(0.4/\Pr)^{2/3}\right]^{1/4}}\left[1+\left(\frac{\text{Re}}{282{,}000}\right)^{5/8}\right]^{4/5}$$

$$= 0.3 + \frac{0.62(3.254\times10^4)^{0.5}(0.7336)^{1/3}}{\left[1+(0.4/0.7336)^{2/3}\right]^{1/4}}\left[1+\left(\frac{3.254\times10^4}{282{,}000}\right)^{5/8}\right]^{4/5} = 107.0$$

and $\qquad h_o = \dfrac{k}{D_o}Nu = \dfrac{0.02439\ \text{W/m}\cdot\text{°C}}{0.116\,\text{m}}(107.0) = 22.50\ \text{W/m}^2\cdot\text{°C}$

Area of the outer surface of the pipe per m length of the pipe is

$$A_o = \pi D_o L = \pi(0.116\,\text{m})(1\,\text{m}) = 0.3644\,\text{m}^2$$

In steady operation, heat transfer from the steam through the pipe and the insulation to the outer surface (by first convection and then conduction) must be equal to the heat transfer from the outer surface to the surroundings (by simultaneous convection and radiation). That is,

$$\dot{Q} = \dot{Q}_{\text{pipe and insulation}} = \dot{Q}_{\text{surface to surroundings}}$$

Using the thermal resistance network, heat transfer from the steam to the outer surface is expressed as

$$R_{conv,i} = \frac{1}{h_i A_i} = \frac{1}{(80\ \text{W/m}^2\text{.°C})\left[\pi(0.04\,\text{m})(1\,\text{m})\right]} = 0.0995\text{°C/W}$$

$$R_{pipe} = \frac{\ln(r_2/r_1)}{2\pi kL} = \frac{\ln(2.3/2)}{2\pi(15\ \text{W/m.°C})(1\,\text{m})} = 0.0015\text{°C/W}$$

$$R_{insulation} = \frac{\ln(r_3/r_2)}{2\pi kL} = \frac{\ln(5.8/2.3)}{2\pi(0.038\ \text{W/m.°C})(1\,\text{m})} = 3.874\text{°C/W}$$

and $\qquad \dot{Q}_{\text{pipe and ins}} = \dfrac{T_{\infty1} - T_s}{R_{conv,i} + R_{pipe} + R_{insulation}} = \dfrac{(250 - T_s)\text{°C}}{(0.0995 + 0.0015 + 3.874)\ \text{°C/W}}$

Heat transfer from the outer surface can be expressed as

$$\dot{Q}_{\text{surface to surr,conv+rad}} = h_o A_o (T_s - T_{surr}) + \varepsilon A_o \sigma (T_s^{\,4} - T_{surr}^{\,4}) = (22.50\ \text{W/m}^2\text{.°C})(0.3644\,\text{m}^2)(T_s - 3)\text{°C}$$
$$+ (0.3)(0.3644\,\text{m}^2)(5.67\times10^{-8}\ \text{W/m}^2\text{.K}^4)\left[(T_s + 273\text{K})^4 - (3 + 273\text{K})^4\right]$$

Solving the two equations above simultaneously, the surface temperature and the heat transfer rate per m length of the pipe are determined to be

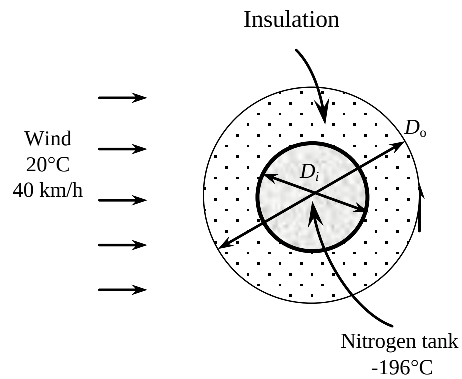
$$T_s = 9.9\text{°C and } \dot{Q} = \mathbf{60.4\ W} \quad \text{(per m length)}$$

**7-101** A spherical tank filled with liquid nitrogen is exposed to winds. The rate of evaporation of the liquid nitrogen due to heat transfer from the air is to be determined for three cases.

***Assumptions*** **1** Steady operating conditions exist. **2** Radiation effects are negligible. **3** Air is an ideal gas with constant properties. **4** The pressure of air is 1 atm.

***Properties*** The properties of air at 1 atm pressure and the free stream temperature of 20°C are (Table A-15)

$$k = 0.02514 \text{ W/m.°C}$$
$$\upsilon = 1.516\times10^{-5} \text{ m}^2\text{/s}$$
$$\mu_\infty = 1.825\times10^{-5} \text{ kg/m.s}$$
$$\mu_{s,@-196\text{°C}} = 5.023\times10^{-6} \text{ kg/m.s}$$
$$\text{Pr} = 0.7309$$




***Analysis*** (*a*) When there is no insulation, $D = D_i = 4$ m, and the Reynolds number is

$$\text{Re} = \frac{V_\infty D}{\upsilon} = \frac{[(40\times1000/3600)\text{m/s}](4\text{ m})}{1.516\times10^{-5}\text{ m}^2\text{/s}} = 2.932\times10^6$$

The Nusselt number is determined from

$$Nu = \frac{hD}{k} = 2 + \left[0.4\text{Re}^{0.5} + 0.06\text{Re}^{2/3}\right]\text{Pr}^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(2.932\times10^6)^{0.5} + 0.06(2.932\times10^6)^{2/3}\right](0.7309)^{0.4}\left(\frac{1.825\times10^{-5}}{5.023\times10^{-6}}\right)^{1/4} = 2333$$

and $$h = \frac{k}{D}Nu = \frac{0.02514\text{ W/m.°C}}{4\text{ m}}(2333) = 14.66\text{ W/m}^2\text{.°C}$$

The rate of heat transfer to the liquid nitrogen is

$$\dot{Q} = hA_s(T_s - T_\infty) = h(\pi D^2)(T_s - T_\infty)$$
$$= (14.66\text{ W/m}^2\text{.°C})[\pi(4\text{ m})^2][(20-(-196)]\text{°C} = 159{,}200\text{ W}$$

The rate of evaporation of liquid nitrogen then becomes

$$\dot{Q} = \dot{m}h_{if} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{if}} = \frac{159.2\text{ kJ/s}}{198\text{ kJ/kg}} = \mathbf{0.804\ \ kg/s}$$

(*b*) Note that after insulation the outer surface temperature and diameter will change. Therefore we need to evaluate dynamic viscosity at a new surface temperature which we will assume to be -100°C. At -100°C, $\mu = 1.189\times10^{-5}$ kg/m.s . Noting that $D = D_0 = 4.1$ m, the Nusselt number becomes

$$\text{Re} = \frac{V_\infty D}{\upsilon} = \frac{[(40\times1000/3600)\text{m/s}](4.1\text{m})}{1.516\times10^{-5}\text{ m}^2\text{/s}} = 3.005\times10^6$$

$$Nu = \frac{hD}{k} = 2 + \left[0.4\text{Re}^{0.5} + 0.06\text{Re}^{2/3}\right]\text{Pr}^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(3.005\times10^6)^{0.5} + 0.06(3.005\times10^6)^{2/3}\right](0.7309)^{0.4}\left(\frac{1.825\times10^{-5}}{1.189\times10^{-5}}\right)^{1/4} = 1910$$

and $$h = \frac{k}{D}Nu = \frac{0.02514\text{ W/m.°C}}{4.1\text{ m}}(1910) = 11.71\text{ W/m}^2\text{.°C}$$

The rate of heat transfer to the liquid nitrogen is

$$A_s = \pi D^2 = \pi(4.1\,\text{m})^2 = 52.81\,\text{m}^2$$

$$\dot{Q} = \frac{T_\infty - T_{s,\tan k}}{R_{insulation} + R_{conv}} = \frac{T_\infty - T_{s,\tan k}}{\dfrac{r_2 - r_1}{4\pi k r_1 r_2} + \dfrac{1}{hA_s}}$$

$$= \frac{[20 - (-196)]°\text{C}}{\dfrac{(2.05 - 2)\,\text{m}}{4\pi(0.035\,\text{W/m.°C})(2.05\,\text{m})(2\,\text{m})} + \dfrac{1}{(11.71\,\text{W/m}^2.°\text{C})(52.81\,\text{m}^2)}} = 7361\text{W}$$

The rate of evaporation of liquid nitrogen then becomes

$$\dot{Q} = \dot{m}h_{if} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{if}} = \frac{7.361\,\text{kJ/s}}{198\,\text{kJ/kg}} = \mathbf{0.0372\ \ kg/s}$$

(*c*) We use the dynamic viscosity value at the new estimated surface temperature of 0°C to be $\mu = 1.729 \times 10^{-5}$ kg/m.s . Noting that $D = D_0$ = 4.04 m in this case, the Nusselt number becomes

$$\text{Re} = \frac{V_\infty D}{\upsilon} = \frac{[(40 \times 1000/3600)\text{m/s}](4.04\,\text{m})}{1.516 \times 10^{-5}\ \text{m}^2/\text{s}} = 2.961 \times 10^6$$

$$Nu = \frac{hD}{k} = 2 + \left[0.4\,\text{Re}^{0.5} + 0.06\,\text{Re}^{2/3}\right]\text{Pr}^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(2.961 \times 10^6)^{0.5} + 0.06(2.961 \times 10^6)^{2/3}\right](0.7309)^{0.4}\left(\frac{1.825 \times 10^{-5}}{1.729 \times 10^{-5}}\right)^{1/4} = 1724$$

and $$h = \frac{k}{D}Nu = \frac{0.02514\,\text{W/m.°C}}{4.04\,\text{m}}(1724) = 10.73\,\text{W/m}^2.°\text{C}$$

The rate of heat transfer to the liquid nitrogen is

$$A_s = \pi D^2 = \pi(4.04\,\text{m})^2 = 51.28\,\text{m}^2$$

$$\dot{Q} = \frac{T_\infty - T_{s,\tan k}}{R_{insulation} + R_{conv}} = \frac{T_\infty - T_{s,\tan k}}{\dfrac{r_2 - r_1}{4\pi k r_1 r_2} + \dfrac{1}{hA_s}}$$

$$= \frac{[20 - (-196)]°\text{C}}{\dfrac{(2.02 - 2)\,\text{m}}{4\pi(0.00005\,\text{W/m.°C})(2.02\,\text{m})(2\,\text{m})} + \dfrac{1}{(10.73\,\text{W/m}^2.°\text{C})(51.28\,\text{m}^2)}} = 27.4\,\text{W}$$

The rate of evaporation of liquid nitrogen then becomes

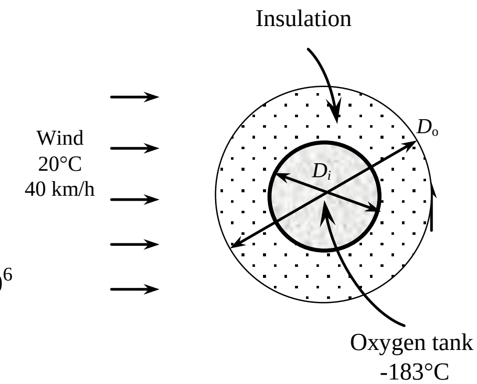
$$\dot{Q} = \dot{m}h_{if} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{if}} = \frac{0.0274\,\text{kJ/s}}{198\,\text{kJ/kg}} = \mathbf{1.38 \times 10^{-4}\ \ kg/s}$$

**7-102** A spherical tank filled with liquid oxygen is exposed to ambient winds. The rate of evaporation of the liquid oxygen due to heat transfer from the air is to be determined for three cases.

***Assumptions*** **1** Steady operating conditions exist. **2** Radiation effects are negligible. **3** Air is an ideal gas with constant properties. **7** The pressure of air is 1 atm.

***Properties*** The properties of air at 1 atm pressure and the free stream temperature of 20°C are (Table A-15)

$$k = 0.02514 \text{ W/m.°C}$$
$$\upsilon = 1.516\times10^{-5} \text{ m}^2\text{/s}$$
$$\mu_\infty = 1.825\times10^{-5} \text{ kg/m.s}$$
$$\mu_{s,@-183°C} = 6.127\times10^{-5} \text{ kg/m.s}$$
$$\Pr = 0.7309$$




***Analysis*** (*a*) When there is no insulation, $D = D_i$ = 4 m, and the Reynolds number is

$$\text{Re} = \frac{V_\infty D}{\upsilon} = \frac{[(40\times1000/3600)\text{m/s}](4\text{ m})}{1.516\times10^{-5}\text{ m}^2\text{/s}} = 2.932\times10^6$$

The Nusselt number is determined from

$$Nu = \frac{hD}{k} = 2 + \left[0.4\text{Re}^{0.5} + 0.06\text{Re}^{2/3}\right]\Pr^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(2.932\times10^6)^{0.5} + 0.06(2.932\times10^6)^{2/3}\right](0.7309)^{0.4}\left(\frac{1.825\times10^{-5}}{1.05\times10^{-5}}\right)^{1/4} = 2220$$

and $$h = \frac{k}{D}Nu = \frac{0.02514\text{ W/m.°C}}{4\text{ m}}(2220) = 13.95\text{ W/m}^2\text{.°C}$$

The rate of heat transfer to the liquid oxygen is

$$\dot{Q} = hA_s(T_s - T_\infty) = h(\pi D^2)(T_s - T_\infty) = (13.95\text{ W/m}^2\text{.°C})[\pi(4\text{ m})^2][(20-(-183)]\text{°C} = 142{,}372\text{ W}$$

The rate of evaporation of liquid oxygen then becomes

$$\dot{Q} = \dot{m}h_{if} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{if}} = \frac{142.4\text{ kJ/s}}{213\text{ kJ/kg}} = \mathbf{0.668\ \ kg/s}$$

(*b*) Note that after insulation the outer surface temperature and diameter will change. Therefore we need to evaluate dynamic viscosity at a new surface temperature which we will assume to be -100°C. At -100°C, $\mu = 1.189\times10^{-5}$ kg/m.s . Noting that $D = D_0$ = 4.1 m, the Nusselt number becomes

$$\text{Re} = \frac{V_\infty D}{\upsilon} = \frac{[(40\times1000/3600)\text{m/s}](4.1\text{m})}{1.516\times10^{-5}\text{ m}^2\text{/s}} = 3.005\times10^6$$

$$Nu = \frac{hD}{k} = 2 + \left[0.4\text{Re}^{0.5} + 0.06\text{Re}^{2/3}\right]\Pr^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(3.005\times10^6)^{0.5} + 0.06(3.005\times10^6)^{2/3}\right](0.7309)^{0.4}\left(\frac{1.825\times10^{-5}}{1.189\times10^{-5}}\right)^{1/4} = 1910$$

and $$h = \frac{k}{D}Nu = \frac{0.02514\text{ W/m.°C}}{4.1\text{ m}}(1910) = 11.71\text{ W/m}^2\text{.°C}$$

The rate of heat transfer to the liquid nitrogen is

$$A_s = \pi D^2 = \pi(4.1\,\text{m})^2 = 52.81\,\text{m}^2$$

$$\dot{Q} = \frac{T_\infty - T_{s,\tan k}}{R_{insulation} + R_{conv}} = \frac{T_\infty - T_{s,\tan k}}{\dfrac{r_2 - r_1}{4\pi k r_1 r_2} + \dfrac{1}{hA_s}}$$

$$= \frac{[20-(-183)]^\circ\text{C}}{\dfrac{(2.05-2)\,\text{m}}{4\pi(0.035\,\text{W/m.}^\circ\text{C})(2.05\,\text{m})(2\,\text{m})} + \dfrac{1}{(11.71\,\text{W/m}^2.^\circ\text{C})(52.81\,\text{m}^2)}} = 6918\,\text{W}$$

The rate of evaporation of liquid nitrogen then becomes

$$\dot{Q} = \dot{m}h_{if} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{if}} = \frac{6.918\,\text{kJ/s}}{213\,\text{kJ/kg}} = \mathbf{0.0325\ kg/s}$$

($c$) Again we use the dynamic viscosity value at the estimated surface temperature of 0°C to be $\mu = 1.729\times10^{-5}$ kg/m.s . Noting that $D = D_0$ = 4.04 m in this case, the Nusselt number becomes

$$\text{Re} = \frac{V_\infty D}{\upsilon} = \frac{[(40\times1000/3600)\text{m/s}](4.04\text{m})}{1.516\times10^{-5}\ \text{m}^2\text{/s}} = 2.961\times10^6$$

$$Nu = \frac{hD}{k} = 2 + \left[0.4\,\text{Re}^{0.5} + 0.06\,\text{Re}^{2/3}\right]\text{Pr}^{0.4}\left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

$$= 2 + \left[0.4(2.961\times10^6)^{0.5} + 0.06(2.961\times10^6)^{2/3}\right](0.713)^{0.4}\left(\frac{1.825\times10^{-5}}{1.729\times10^{-5}}\right)^{1/4} = 1724$$

and $$h = \frac{k}{D}Nu = \frac{0.02514\,\text{W/m.}^\circ\text{C}}{4.04\,\text{m}}(1724) = 10.73\,\text{W/m}^2.^\circ\text{C}$$

The rate of heat transfer to the liquid nitrogen is

$$A_s = \pi D^2 = \pi(4.04\,\text{m})^2 = 51.28\,\text{m}^2$$

$$\dot{Q} = \frac{T_\infty - T_{s,\tan k}}{R_{insulation} + R_{conv}} = \frac{T_\infty - T_{s,\tan k}}{\dfrac{r_2 - r_1}{4\pi k r_1 r_2} + \dfrac{1}{hA_s}}$$

$$= \frac{[20-(-183)]^\circ\text{C}}{\dfrac{(2.02-2)\,\text{m}}{4\pi(0.00005\,\text{W/m.}^\circ\text{C})(2.02\,\text{m})(2\,\text{m})} + \dfrac{1}{(10.73\,\text{W/m}^2.^\circ\text{C})(51.28\,\text{m}^2)}} = 25.8\,\text{W}$$

The rate of evaporation of liquid oxygen then becomes

$$\dot{Q} = \dot{m}h_{if} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{if}} = \frac{0.0258\,\text{kJ/s}}{213\,\text{kJ/kg}} = \mathbf{1.21\times10^{-4}\ kg/s}$$

**7-103** A circuit board houses 80 closely spaced logic chips on one side. All the heat generated is conducted across the circuit board and is dissipated from the back side of the board to the ambient air, which is forced to flow over the surface by a fan. The temperatures on the two sides of the circuit board are to be determined.

***Assumptions*** **1** Steady operating conditions exist. **2** The critical Reynolds number is $Re_{cr} = 5\times10^5$. **3** Radiation effects are negligible. **4** Air is an ideal gas with constant properties. **7** The pressure of air is 1 atm.

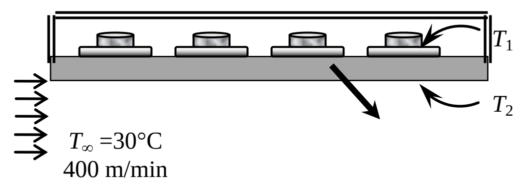
***Properties*** Assuming a film temperature of 40°C, the properties of air are (Table A-15)

$$k = 0.02662 \text{ W/m.°C}$$

$$\upsilon = 1.702\times10^{-5} \text{ m}^2\text{/s}$$

$$\Pr = 0.7255$$

***Analysis*** The Reynolds number is




$$\text{Re}_L = \frac{V_\infty L}{\upsilon} = \frac{[(400/60)\text{ m/s}](0.18\text{m})}{1.702\times10^{-5}\text{ m}^2\text{/s}} = 7.051\times10^4$$

which is less than the critical Reynolds number. Therefore, the flow is laminar. Using the proper relation for Nusselt number, heat transfer coefficient is determined to be

$$Nu = \frac{hL}{k} = 0.664\text{Re}_L^{0.5}\Pr^{1/3} = 0.664(7.051\times10^4)^{0.5}(0.7255)^{1/3} = 158.4$$

$$h = \frac{k}{L}Nu = \frac{0.02662\text{ W/m.°C}}{0.18\text{ m}}(158.4) = 23.43\text{ W/m}^2\text{.°C}$$

The temperatures on the two sides of the circuit board are

$$\dot{Q} = hA_s(T_2 - T_\infty) \rightarrow T_2 = T_\infty + \frac{\dot{Q}}{hA_s}$$

$$= 30°\text{C} + \frac{(80\times0.06)\text{ W}}{(23.43\text{ W/m}^2\text{.°C})(0.12\text{ m})(0.18\text{m})} = \mathbf{39.48°C}$$

$$\dot{Q} = \frac{kA_s}{L}(T_1 - T_2) \rightarrow T_1 = T_2 + \frac{\dot{Q}L}{kA_s}$$

$$= 39.48°\text{C} + \frac{(80\times0.06\text{ W})(0.003\text{m})}{(16\text{ W/m.°C})(0.12\text{ m})(0.18\text{m})} = \mathbf{39.52°C}$$

**7-104E** The equivalent wind chill temperature of an environment at 10°F at various winds speeds are

**V** = 10 mph: $T_{equiv} = 91.4 - (91.4 - T_{ambient})(0.475 - 0.0203V + 0.304\sqrt{V})$

$$= 91.4 - \ 91.4 - (10°\text{ F}) \ \ 0.475 - 0.0203(10\text{ mph}) + 0.304\sqrt{10\text{ mph}} \ = -\mathbf{9°\ F}$$

**V** = 20 mph: $T_{equiv} = 91.4 - \ 91.4 - (10°\text{ F}) \ \ 0.475 - 0.0203(20\text{ mph}) + 0.304\sqrt{20\text{ mph}} \ = -\mathbf{24.9°\ F}$

**V** = 30 mph: $T_{equiv} = 91.4 - \ 91.4 - (10°\text{ F}) \ \ 0.475 - 0.0203(30\text{ mph}) + 0.304\sqrt{30\text{ mph}} \ = -\mathbf{33.2°\ F}$

**V** = 40 mph: $T_{equiv} = 91.4 - \ 91.4 - (10°\text{ F}) \ \ 0.475 - 0.0203(40\text{ mph}) + 0.304\sqrt{40\text{ mph}} \ = -\mathbf{37.7°\ F}$

In the last 3 cases, the person needs to be concerned about the possibility of freezing.

**7-105E** "!PROBLEM 7-105E"

"ANALYSIS"
T_equiv=91.4-(91.4-T_ambient)*(0.475 - 0.0203*Vel+0.304*sqrt(Vel))

| Vel [mph] | $T_{ambient}$ [F] | $T_{equiv}$ [F] |
|---|---|---|
| 4 | 20 | 19.87 |
| 14.67 | 20 | -4.383 |
| 25.33 | 20 | -15.05 |
| 36 | 20 | -20.57 |
| 46.67 | 20 | -23.15 |
| 57.33 | 20 | -23.77 |
| 68 | 20 | -22.94 |
| 78.67 | 20 | -21.01 |
| 89.33 | 20 | -18.19 |
| 100 | 20 | -14.63 |
| 4 | 40 | 39.91 |
| 14.67 | 40 | 22.45 |
| 25.33 | 40 | 14.77 |
| 36 | 40 | 10.79 |
| 46.67 | 40 | 8.935 |
| 57.33 | 40 | 8.493 |
| 68 | 40 | 9.086 |
| 78.67 | 40 | 10.48 |
| 89.33 | 40 | 12.51 |
| 100 | 40 | 15.07 |
| 4 | 60 | 59.94 |
| 14.67 | 60 | 49.28 |
| 25.33 | 60 | 44.59 |
| 36 | 60 | 42.16 |
| 46.67 | 60 | 41.02 |
| 57.33 | 60 | 40.75 |
| 68 | 60 | 41.11 |
| 78.67 | 60 | 41.96 |
| 89.33 | 60 | 43.21 |
| 100 | 60 | 44.77 |

**7-106 …. 7-110 Design and Essay Problems**