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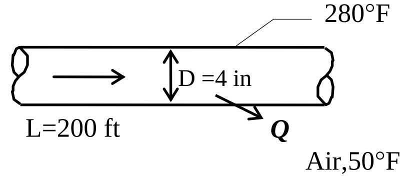
سایت آموزش مهندسی مکانیک

1-87E A 200-ft long section of a steam pipe passes through an open space at a specified temperature. The rate of heat loss from the steam pipe and the annual cost of this energy lost are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is disregarded. **3** The convection heat transfer coefficient is constant and uniform over the surface.

Analysis (*a*) The rate of heat loss from the steam pipe is



$$A_s = \pi DL = \pi(4/12\text{ ft})(200\text{ ft}) = 209.4\text{ ft}^2$$

$$\dot{Q}_{\text{pipe}} = hA_s(T_s - T_{air}) = (6\text{ Btu/h.ft}^2.°\text{F})(209.4\text{ ft}^2)(280-50)°\text{F}$$
$$= \mathbf{289{,}000\,Btu/h}$$

(*b*) The amount of heat loss per year is

$$Q = \dot{Q}\Delta t = (289{,}000\text{ Btu / h})(365\times 24\text{ h / yr}) = 2.532\times 10^9\text{ Btu / yr}$$

The amount of gas consumption per year in the furnace that has an efficiency of 86% is

$$\text{Annual Energy Loss} = \frac{2.532\times 10^9\text{ Btu/yr}}{0.86}\left(\frac{1\text{ therm}}{100{,}000\text{Btu}}\right) = 29{,}438\text{ therms/yr}$$

Then the annual cost of the energy lost becomes

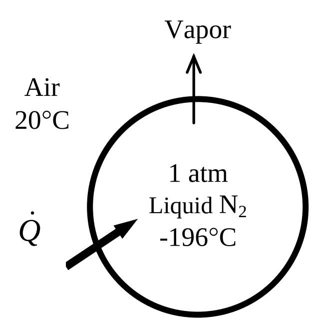
$$\text{Energy cost} = (\text{Annual energy loss})(\text{Unit cost of energy})$$
$$= (29{,}438\text{ therms / yr})(\$0.58\text{ / therm}) = \mathbf{\$17{,}074\text{ / yr}}$$

1-88 A 4-m diameter spherical tank filled with liquid nitrogen at 1 atm and -196°C is exposed to convection with ambient air. The rate of evaporation of liquid nitrogen in the tank as a result of the heat transfer from the ambient air is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is disregarded. **3** The convection heat transfer coefficient is constant and uniform over the surface. **4** The temperature of the thin-shelled spherical tank is nearly equal to the temperature of the nitrogen inside.

Properties The heat of vaporization and density of liquid nitrogen at 1 atm are given to be 198 kJ/kg and 810 kg/m^3, respectively.

Analysis The rate of heat transfer to the nitrogen tank is



$$A_s = \pi D^2 = \pi(4\text{ m})^2 = 50.27\text{ m}^2$$

$$\dot{Q} = hA_s(T_s - T_{\text{air}}) = (25\text{ W/m}^2.°\text{C})(50.27\text{ m}^2)[20-(-196)]°\text{C}$$
$$= \mathbf{271{,}430\,W}$$

Then the rate of evaporation of liquid nitrogen in the tank is determined to be

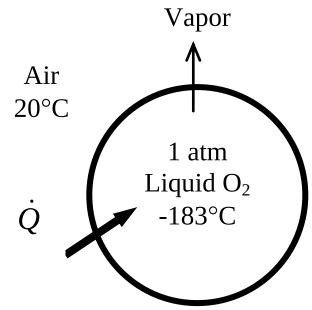
$$\dot{Q} = \dot{m}h_{fg} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{fg}} = \frac{271.430\text{ kJ/s}}{198\text{ kJ/kg}} = \mathbf{1.37\,kg/s}$$

1-89 A 4-m diameter spherical tank filled with liquid oxygen at 1 atm and -183°C is exposed to convection with ambient air. The rate of evaporation of liquid oxygen in the tank as a result of the heat transfer from the ambient air is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by radiation is disregarded. **3** The convection heat transfer coefficient is constant and uniform over the surface. **4** The temperature of the thin-shelled spherical tank is nearly equal to the temperature of the oxygen inside.

Properties The heat of vaporization and density of liquid oxygen at 1 atm are given to be 213 kJ/kg and 1140 kg/m^3, respectively.

Analysis The rate of heat transfer to the oxygen tank is



$$A_s = \pi D^2 = \pi(4\,\text{m})^2 = 50.27\,\text{m}^2$$

$$\dot{Q} = hA_s(T_s - T_{\text{air}}) = (25\,\text{W/m}^2.°\text{C})(50.27\,\text{m}^2)[20-(-183)]°\text{C}$$
$$= \mathbf{255{,}120\,W}$$

Then the rate of evaporation of liquid oxygen in the tank is determined to be

$$\dot{Q} = \dot{m}h_{fg} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{fg}} = \frac{255.120\ \text{kJ/s}}{213\ \text{kJ/kg}} = \mathbf{1.20\ kg/s}$$

1-90

```
"GIVEN"
D=4 "[m]"
T_s=-196 "[C]"
"T_air=20 [C], parameter to be varied"
h=25 "[W/m^2-C]"

"PROPERTIES"
h_fg=198 "[kJ/kg]"

"ANALYSIS"
A=pi*D^2
Q_dot=h*A*(T_air-T_s)
m_dot_evap=(Q_dot*Convert(J/s, kJ/s))/h_fg
```

T_{air} [C]	m_{evap} [kg/s]
0	1.244
2.5	1.26
5	1.276
7.5	1.292
10	1.307
12.5	1.323
15	1.339
17.5	1.355
20	1.371
22.5	1.387
25	1.403
27.5	1.418
30	1.434
32.5	1.45
35	1.466

1-91 A person with a specified surface temperature is subjected to radiation heat transfer in a room at specified wall temperatures. The rate of radiation heat loss from the person is to be determined.

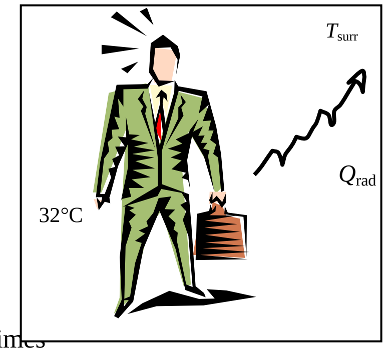
Assumptions **1** Steady operating conditions exist. **2** Heat transfer by convection is disregarded. **3** The emissivity of the person is constant and uniform over the exposed surface.

Properties The average emissivity of the person is given to be 0.7.

Analysis Noting that the person is completely enclosed by the surrounding surfaces, the net rates of radiation heat transfer from the body to the surrounding walls, ceiling, and the floor in both cases are

(*a*) T_{surr} = 300 K

$$\begin{aligned}\dot{Q}_{rad} &= \varepsilon\sigma A_s(T_s^4 - T_{surr}^4)\\ &= (0.7)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.7\,\text{m}^2)[(32+273)^4 - (300\,\text{K})^4]\text{K}^4\\ &= \mathbf{37.4\ W}\end{aligned}$$



(*b*) T_{surr} = 280 K

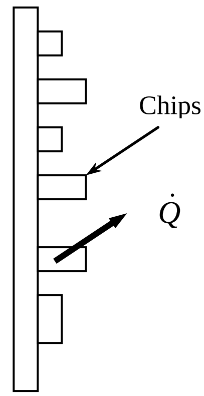
$$\begin{aligned}\dot{Q}_{rad} &= \varepsilon\sigma A_s(T_s^4 - T_{surr}^4)\\ &= (0.7)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.7\,\text{m}^2)[(32+273)^4 - (280\,\text{K})^4]\text{K}^4\\ &= \mathbf{169\ W}\end{aligned}$$

Discussion Note that the radiation heat transfer goes up by more than 4 times as the temperature of the surrounding surfaces drops from 300 K to 280 K.

1-92 A circuit board houses 80 closely spaced logic chips on one side, each dissipating 0.06 W. All the heat generated in the chips is conducted across the circuit board. The temperature difference between the two sides of the circuit board is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Thermal properties of the board are constant. **3** All the heat generated in the chips is conducted across the circuit board.

Properties The effective thermal conductivity of the board is given to be k = 16 W/m·°C.



Analysis The total rate of heat dissipated by the chips is

$$\dot{Q} = 80 \times (0.06\ \text{W}) = 4.8\ \text{W}$$

Then the temperature difference between the front and back surfaces of the board is

$$A = (0.12\ \text{m})(0.18\ \text{m}) = 0.0216\ \text{m}^2$$

$$\dot{Q} = kA\frac{\Delta T}{L} \longrightarrow \Delta T = \frac{\dot{Q}L}{kA} = \frac{(4.8\ \text{W})(0.003\ \text{m})}{(16\ \text{W/m.°C})(0.0216\ \text{m}^2)} = \mathbf{0.042°C}$$

Discussion Note that the circuit board is nearly isothermal.

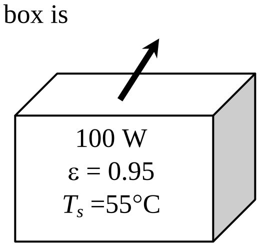
1-93 A sealed electronic box dissipating a total of 100 W of power is placed in a vacuum chamber. If this box is to be cooled by radiation alone and the outer surface temperature of the box is not to exceed 55°C, the temperature the surrounding surfaces must be kept is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer by convection is disregarded. **3** The emissivity of the box is constant and uniform over the exposed surface. **4** Heat transfer from the bottom surface of the box to the stand is negligible.

Properties The emissivity of the outer surface of the box is given to be 0.95.

Analysis Disregarding the base area, the total heat transfer area of the electronic box is

$$A_s = (0.4\ \text{m})(0.4\ \text{m}) + 4 \times (0.2\ \text{m})(0.4\ \text{m}) = 0.48\ \text{m}^2$$



The radiation heat transfer from the box can be expressed as

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

$$100\ \text{W} = (0.95)(5.67 \times 10^{-8}\ \text{W/m}^2.\text{K}^4)(0.48\ \text{m}^2)\left[(55 + 273\ \text{K})^4 - T_{surr}{}^4\right]$$

which gives T_{surr} = **296.3 K = 23.3°C**. Therefore, the temperature of the surrounding surfaces must be less than 23.3°C.

1-94 Using the conversion factors between W and Btu/h, m and ft, and K and R, the Stefan-Boltzmann constant $\sigma = 5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4$ is to be expressed in the English unit, $\text{Btu/h.ft}^2.\text{R}^4$.

Analysis The conversion factors for W, m, and K are given in conversion tables to be

$$1\ \text{W} = 3.41214\ \text{Btu/h}$$
$$1\ \text{m} = 3.2808\ \text{ft}$$
$$1\ \text{K} = 1.8\ \text{R}$$

Substituting gives the Stefan-Boltzmann constant in the desired units,

$$\sigma = 5.67\ \text{W/m}^2.\text{K}^4 = 5.67\times\frac{3.41214\ \text{Btu/h}}{(3.2808\ \text{ft})^2(1.8\ \text{R})^4} = \mathbf{0.171\ Btu/h.ft^2.R^4}$$

1-95 Using the conversion factors between W and Btu/h, m and ft, and °C and °F, the convection coefficient in SI units is to be expressed in Btu/h.ft^2.°F.

Analysis The conversion factors for W and m are straightforward, and are given in conversion tables to be

$$1\ \text{W} = 3.41214\ \text{Btu/h}$$
$$1\ \text{m} = 3.2808\ \text{ft}$$

The proper conversion factor between °C into °F in this case is

$$1°\text{C} = 1.8°\text{F}$$

since the °C in the unit W/m^2.°C represents *per °C change in temperature*, and 1°C change in temperature corresponds to a change of 1.8°F. Substituting, we get

$$1\ \text{W/m}^2.°\text{C} = \frac{3.41214\ \text{Btu/h}}{(3.2808\ \text{ft})^2(1.8\ °\text{F})} = 0.1761\ \text{Btu/h.ft}^2.°\text{F}$$

which is the desired conversion factor. Therefore, the given convection heat transfer coefficient in English units is

$$h = 20\ \text{W/m}^2.°\text{C} = 20\times0.1761\ \text{Btu/h.ft}^2.°\text{F} = \mathbf{3.52\ Btu/h.ft^2.°F}$$

Simultaneous Heat Transfer Mechanisms

1-96C All three modes of heat transfer can not occur simultaneously in a medium. A medium may involve two of them simultaneously.

1-97C (*a*) Conduction and convection: No. (*b*) Conduction and radiation: Yes. Example: A hot surface on the ceiling. (*c*) Convection and radiation: Yes. Example: Heat transfer from the human body.

1-98C The human body loses heat by convection, radiation, and evaporation in both summer and winter. In summer, we can keep cool by dressing lightly, staying in cooler environments, turning a fan on, avoiding humid places and direct exposure to the sun. In winter, we can keep warm by dressing heavily, staying in a warmer environment, and avoiding drafts.

1-99C The fan increases the air motion around the body and thus the convection heat transfer coefficient, which increases the rate of heat transfer from the body by convection and evaporation. In rooms with high ceilings, ceiling fans are used in winter to force the warm air at the top downward to increase the air temperature at the body level. This is usually done by forcing the air up which hits the ceiling and moves downward in a gently manner to avoid drafts.

1-100 The total rate of heat transfer from a person by both convection and radiation to the surrounding air and surfaces at specified temperatures is to be determined.

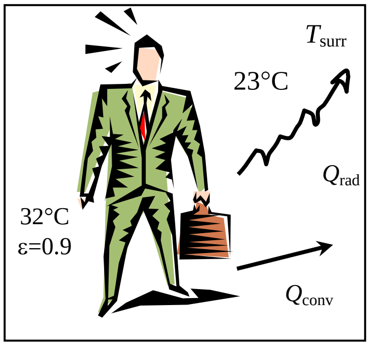
Assumptions 1 Steady operating conditions exist. **2** The person is completely surrounded by the interior surfaces of the room. **3** The surrounding surfaces are at the same temperature as the air in the room. **4** Heat conduction to the floor through the feet is negligible. **5** The convection coefficient is constant and uniform over the entire surface of the person.

Properties The emissivity of a person is given to be ε = 0.9.

Analysis The person is completely enclosed by the surrounding surfaces, and he or she will lose heat to the surrounding air by convection, and to the surrounding surfaces by radiation. The total rate of heat loss from the person is determined from

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A_s (T_s^4 - T_{\text{surr}}^4) = (0.90)(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1.7\,\text{m}^2)[(32+273)^4 - (23+273)^4]\text{K}^4$$
$$= 84.8\,\text{W}$$

$$\dot{Q}_{\text{conv}} = hA_s\Delta T = (5\text{W/m}^2\cdot\text{K})(1.7\text{m}^2)(32-23)°\text{C} = 76.5\text{W}$$



and

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 84.8 + 76.5 = \mathbf{161.3\ W}$$

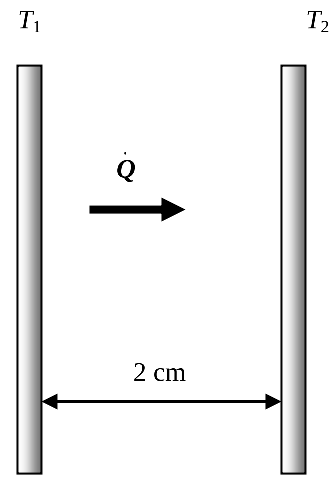
Discussion Note that heat transfer from the person by evaporation, which is of comparable magnitude, is not considered in this problem.

1-101 Two large plates at specified temperatures are held parallel to each other. The rate of heat transfer between the plates is to be determined for the cases of still air, regular insulation, and super insulation between the plates.

Assumptions **1** Steady operating conditions exist since the plate temperatures remain constant. **2** Heat transfer is one-dimensional since the plates are large. **3** The surfaces are black and thus ε = 1. **4** There are no convection currents in the air space between the plates.

Properties The thermal conductivities are *k* = 0.00015 W/m·°C for super insulation, *k* = 0.01979 W/m·°C at -50°C (Table A-15) for air, and *k* = 0.036 W/m·°C for fiberglass insulation (Table A-16).

Analysis (*a*) Disregarding any natural convection currents, the rates of conduction and radiation heat transfer



$$\dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{L} = (0.01979\,\text{W/m}^2.°\text{C})(1\,\text{m}^2)\frac{(290-150)\,\text{K}}{0.02\,\text{m}} = 139\,\text{W}$$

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A_s(T_1^4 - T_2^4)$$
$$= 1(5.67\times10^{-8}\ \text{W/m}^2.\text{K}^4)(1\text{m}^2)\left[(290\,\text{K})^4 - (150\,\text{K})^4\right] = 372\,\text{W}$$

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{cond}} + \dot{Q}_{\text{rad}} = 139 + 372 = \mathbf{511\,W}$$

(*b*) When the air space between the plates is evacuated, there will be radiation heat transfer only. Therefore,

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{rad}} = \mathbf{372\ W}$$

(*c*) In this case there will be conduction heat transfer through the fiberglass insulation only,

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{L} = (0.036\ \text{W / m.}^{\text{o}}\,\text{C})(1\ \text{m}^2)\frac{(290-150)\ \text{K}}{0.02\ \text{m}} = \mathbf{252\ W}$$

(*d*) In the case of superinsulation, the rate of heat transfer will be

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{L} = (0.00015\ \text{W / m.}°\text{C})(1\ \text{m}^2)\frac{(290-150)\ \text{K}}{0.02\ \text{m}} = \mathbf{1.05\ W}$$

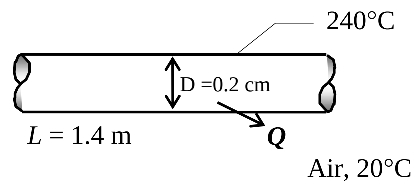
Discussion Note that superinsulators are very effective in reducing heat transfer between to surfaces.

1-102 The convection heat transfer coefficient for heat transfer from an electrically heated wire to air is to be determined by measuring temperatures when steady operating conditions are reached and the electric power consumed.

Assumptions 1 Steady operating conditions exist since the temperature readings do not change with time. **2** Radiation heat transfer is negligible.

Analysis In steady operation, the rate of heat loss from the wire equals the rate of heat generation in the wire as a result of resistance heating. That is,

$$\dot{Q} = \dot{E}_{\text{generated}} = VI = (110\text{ V})(3\text{ A}) = 330\text{ W}$$



The surface area of the wire is

$$A_s = (\pi D)L = \pi(0.002\,\text{m})(1.4\,\text{m}) = 0.00880\text{m}^2$$

The Newton's law of cooling for convection heat transfer is expressed as

$$\dot{Q} = hA_s(T_s - T_\infty)$$

Disregarding any heat transfer by radiation , the convection heat transfer coefficient is determined to be

$$h = \frac{\dot{Q}}{A_s(T_1 - T_\infty)} = \frac{330\,\text{W}}{(0.00880\text{m}^2)(240-20)°\text{C}} = \mathbf{170.5\,W/m^2.°C}$$

Discussion If the temperature of the surrounding surfaces is equal to the air temperature in the room, the value obtained above actually represents the combined convection and radiation heat transfer coefficient.

1-103

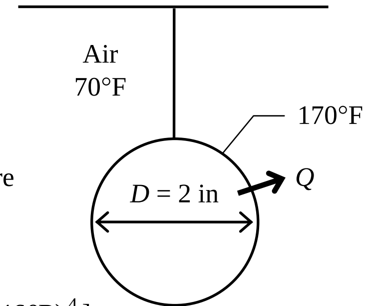
```
"GIVEN"
L=1.4 "[m]"
D=0.002 "[m]"
T_infinity=20 "[C]"
"T_s=240 [C], parameter to be varied"
V=110 "[Volt]"
I=3 "[Ampere]"

"ANALYSIS"
Q_dot=V*I
A=pi*D*L
Q_dot=h*A*(T_s-T_infinity)
```

T_s [C]	h [W/m^2.C]
100	468.9
120	375.2
140	312.6
160	268
180	234.5
200	208.4
220	187.6
240	170.5
260	156.3
280	144.3
300	134

1-104E A spherical ball whose surface is maintained at a temperature of 170°F is suspended in the middle of a room at 70°F. The total rate of heat transfer from the ball is to be determined.

Assumptions **1** Steady operating conditions exist since the ball surface and the surrounding air and surfaces remain at constant temperatures. **2** The thermal properties of the ball and the convection heat transfer coefficient are constant and uniform.



Properties The emissivity of the ball surface is given to be ε = 0.8.

Analysis The heat transfer surface area is

$$A_s = \pi D^2 = \pi(2/12 \text{ ft})^2 = 0.08727 \text{ ft}^2$$

Under steady conditions, the rates of convection and radiation heat transfer are

$$\dot{Q}_{\text{conv}} = hA_s\Delta T = (12 \text{ Btu/h.ft}^2\cdot{}^\circ\text{F})(0.08727 \text{ ft}^2)(170-70)^\circ\text{F} = 104.7 \text{ Btu/h}$$

$$\begin{aligned}\dot{Q}_{\text{rad}} &= \varepsilon\sigma A_s(T_s^4 - T_o^4)\\ &= 0.8(0.08727 \text{ ft}^2)(0.1714\times10^{-8} \text{ Btu/h.ft}^2\cdot\text{R}^4)[(170+460 \text{ R})^4 - (70+460 \text{ R})^4]\\ &= 9.4 \text{ Btu/h}\end{aligned}$$

Therefore, $\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 104.7 + 9.4 = \mathbf{114.1\ Btu/h}$

Discussion Note that heat loss by convection is several times that of heat loss by radiation. The radiation heat loss can further be reduced by coating the ball with a low-emissivity material.

1-105 A 1000-W iron is left on the iron board with its base exposed to the air at 20°C. The temperature of the base of the iron is to be determined in steady operation.

Assumptions **1** Steady operating conditions exist. **2** The thermal properties of the iron base and the convection heat transfer coefficient are constant and uniform. **3** The temperature of the surrounding surfaces is the same as the temperature of the surrounding air.

Properties The emissivity of the base surface is given to be ε = 0.6.

Analysis At steady conditions, the 1000 W energy supplied to the iron will be dissipated to the surroundings by convection and radiation heat transfer. Therefore,

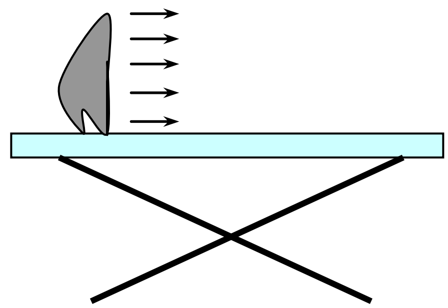
$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 1000 \text{ W}$$

where

$$\dot{Q}_{\text{conv}} = hA_s\Delta T = (35 \text{ W/m}^2 \cdot \text{K})(0.02 \text{ m}^2)(T_s - 293 \text{ K}) = 0.7(T_s - 293 \text{ K}) \text{ W}$$

and

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A_s(T_s^4 - T_o^4) = 0.6(0.02\text{m}^2)(5.67\times10^{-8} \text{ W/m}^2 \cdot \text{K}^4)[T_s^4 - (293\text{K})^4]$$
$$= 0.06804\times10^{-8}[T_s^4 - (293\text{K})^4] \text{ W}$$



Substituting,

$$1000 \text{ W} = 0.7(T_s - 293 \text{ K}) + 0.06804\times10^{-8}[T_s^4 - (293 \text{ K})^4]$$

Solving by trial and error gives

$$T_s = \mathbf{947\ K} = \mathbf{674^\circ\ C}$$

Discussion We note that the iron will dissipate all the energy it receives by convection and radiation when its surface temperature reaches 947 K.

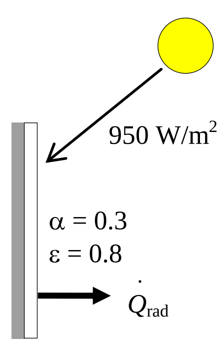
1-106 A spacecraft in space absorbs solar radiation while losing heat to deep space by thermal radiation. The surface temperature of the spacecraft is to be determined when steady conditions are reached..

Assumptions **1** Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values. **2** Thermal properties of the wall are constant.

Properties The outer surface of a spacecraft has an emissivity of 0.8 and an absorptivity of 0.3.

Analysis When the heat loss from the outer surface of the spacecraft by radiation equals the solar radiation absorbed, the surface temperature can be determined from

$$\dot{Q}_{\text{solar absorbed}} = \dot{Q}_{\text{rad}}$$
$$\alpha\dot{Q}_{\text{solar}} = \varepsilon\sigma A_s(T_s^4 - T_{\text{space}}^4)$$
$$0.3\times A_s \times (950 \text{W/m}^2) = 0.8\times A_s \times (5.67\times10^{-8} \text{ W/m}^2 \cdot \text{K}^4)[T_s^4 - (0\text{K})^4]$$



Canceling the surface area A and solving for T_s gives

$$T_s = \mathbf{281.5\ K}$$

1-107 A spherical tank located outdoors is used to store iced water at 0°C. The rate of heat transfer to the iced water in the tank and the amount of ice at 0°C that melts during a 24-h period are to be determined.

Assumptions **1** Steady operating conditions exist since the surface temperatures of the wall remain constant at the specified values. **2** Thermal properties of the tank and the convection heat transfer coefficient is constant and uniform. **3** The average surrounding surface temperature for radiation exchange is 15°C. **4** The thermal resistance of the tank is negligible, and the entire steel tank is at 0°C.

Properties The heat of fusion of water at atmospheric pressure is $h_{if} = 333.7 \text{ kJ/kg}$. The emissivity of the outer surface of the tank is 0.6.

Analysis (a) The outer surface area of the spherical tank is

$$A_s = \pi D^2 = \pi(3.02\,\text{m})^2 = 28.65\,\text{m}^2$$

Then the rates of heat transfer to the tank by convection and radiation become

$$\dot{Q}_{\text{conv}} = hA_s(T_\infty - T_s) = (30\,\text{W/m}^2.°\text{C})(28.65\,\text{m}^2)(25-0)°\text{C} = 21{,}488\,\text{W}$$

$$\dot{Q}_{\text{rad}} = \varepsilon A_s \sigma(T_{surr}^4 - T_s^4) = (0.6)(28.65\,\text{m}^2)(5.67\times10^{-8}\,\text{W/m}^2.\text{K}^4)[(288\,\text{K})^4 - (273\,\text{K})^4] = 1292\,\text{W}$$

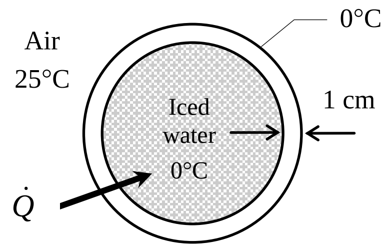
$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 21{,}488 + 1292 = 22{,}780\,\text{W}$$

(b) The amount of heat transfer during a 24-hour period is

$$Q = \dot{Q}\Delta t = (22.78\,\text{kJ/s})(24\times3600\,\text{s}) = 1{,}968{,}000\,\text{kJ}$$

Then the amount of ice that melts during this period becomes

$$Q = mh_{if} \longrightarrow m = \frac{Q}{h_{if}} = \frac{1{,}968{,}000\,\text{kJ}}{333.7\,\text{kJ/kg}} = \mathbf{5898\,kg}$$



Discussion The amount of ice that melts can be reduced to a small fraction by insulating the tank.

1-108 The roof of a house with a gas furnace consists of a 15-cm thick concrete that is losing heat to the outdoors by radiation and convection. The rate of heat transfer through the roof and the money lost through the roof that night during a 14 hour period are to be determined.

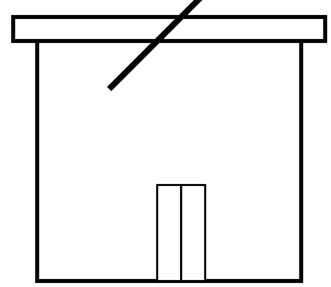
Assumptions **1** Steady operating conditions exist. **2** The emissivity and thermal conductivity of the roof are constant.

Properties The thermal conductivity of the concrete is given to be k = 2 W/m·°C. The emissivity of the outer surface of the roof is given to be 0.9.

Analysis In steady operation, heat transfer from the outer surface of the roof to the surroundings by convection and radiation must be equal to the heat transfer through the roof by conduction. That is,

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

The inner surface temperature of the roof is given to be $T_{s,in}$ = 15°C. Letting $T_{s,out}$ denote the outer surface temperatures of the roof, the energy balance above can be expressed as



$$\dot{Q} = kA\frac{T_{s,in} - T_{s,out}}{L} = h_o A(T_{s,out} - T_{surr}) + \varepsilon A\sigma(T_{s,out}{}^4 - T_{surr}{}^4)$$

$$\dot{Q} = (2\text{ W/m.°C})(300\text{ m}^2)\frac{15°\text{C} - T_{s,out}}{0.15\text{ m}}$$
$$= (15\text{ W/m}^2\text{.°C})(300\text{ m}^2)(T_{s,out} - 10)°\text{C}$$
$$+ (0.9)(300\text{ m}^2)(5.67\times10^{-8}\text{ W/m}^2\text{.K}^4)\ (T_{s,out} + 273\text{ K})^4 - (255\text{ K})^4$$

Solving the equations above using an equation solver (or by trial and error) gives

$$\dot{Q} = \mathbf{25{,}450\ W} \text{ and } T_{s,\ out} = \mathbf{8.64°\ C}$$

Then the amount of natural gas consumption during a 1-hour period is

$$E_{gas} = \frac{Q_{total}}{0.85} = \frac{\dot{Q}\Delta t}{0.85} = \frac{(25.450\,\text{kJ/s})(14\times3600\text{s})}{0.85}\left(\frac{1\,\text{therm}}{105{,}500\text{kJ}}\right) = 14.3\,\text{therms}$$

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

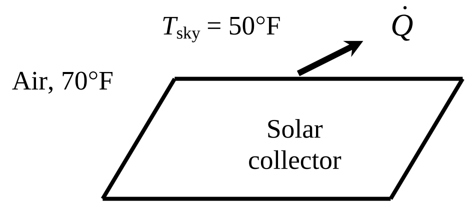
$$\text{Money lost} = (14.3\text{ therms})(\$0.60/\text{therm}) = \mathbf{\$8.58}$$

1-109E A flat plate solar collector is placed horizontally on the roof of a house. The rate of heat loss from the collector by convection and radiation during a calm day are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The emissivity and convection heat transfer coefficient are constant and uniform. **3** The exposed surface, ambient, and sky temperatures remain constant.

Properties The emissivity of the outer surface of the collector is given to be 0.9.

Analysis The exposed surface area of the collector is



$$A_s = (5\,\text{ft})(15\text{ft}) = 75\,\text{ft}^2$$

Noting that the exposed surface temperature of the collector is 100°F, the total rate of heat loss from the collector the environment by convection and radiation becomes

$$\dot{Q}_{\text{conv}} = hA_s(T_\infty - T_s) = (2.5\,\text{Btu/h.ft}^2.°\text{F})(75\,\text{ft}^2)(100-70)°\text{F} = 5625\,\text{Btu/h}$$

$$\dot{Q}_{\text{rad}} = \varepsilon A_s \sigma(T_{surr}^4 - T_s^4) = (0.9)(75\,\text{ft}^2)(0.1714\times10^{-8}\,\text{Btu/h.ft}^2.\text{R}^4)[(100+460\,\text{R})^4 - (50+460\,\text{R})^4]$$
$$= 3551\,\text{Btu/h}$$

and

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{conv}} + \dot{Q}_{\text{rad}} = 5625 + 3551 = \mathbf{9176\ Btu/h}$$

Problem Solving Techniques and EES

1-110C Despite the convenience and capability the engineering software packages offer, they are still just tools, and they will not replace the traditional engineering courses. They will simply cause a shift in emphasis in the course material from mathematics to physics. They are of great value in engineering practice, however, as engineers today rely on software packages for solving large and complex problems in a short time, and perform optimization studies efficiently.

1-111 Determine a positive real root of the following equation using EES:

$$2x^3 - 10x^{0.5} - 3x = -3$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
2*x^3-10*x^0.5-3*x = -3
```

Answer: x = 2.063 (using an initial guess of x=2)

1-112 Solve the following system of 2 equations with 2 unknowns using EES:

$$x^3 - y^2 = 7.75$$

$$3xy + y = 3.5$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
x^3-y^2=7.75
3*x*y+y=3.5
```

Answer x=2 y=0.5

1-113 Solve the following system of 3 equations with 3 unknowns using EES:

$$2x - y + z = 5$$

$$3x^2 + 2y = z + 2$$

$$xy + 2z = 8$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
2*x-y+z=5
3*x^2+2*y=z+2
x*y+2*z=8
```

Answer x=1.141, y=0.8159, z=3.535

1-114 Solve the following system of 3 equations with 3 unknowns using EES:

$$x^2y - z = 1$$

$$x - 3y^{0.5} + xz = -2$$

$$x + y - z = 2$$

Solution by EES Software (Copy the following lines and paste on a blank EES screen to verify solution):

```
x^2*y-z=1
x-3*y^0.5+x*z=-2
x+y-z=2
```

Answer x=1, y=1, z=0

Special Topic: Thermal Comfort

1-115C The metabolism refers to the burning of foods such as carbohydrates, fat, and protein in order to perform the necessary bodily functions. The metabolic rate for an average man ranges from 108 W while reading, writing, typing, or listening to a lecture in a classroom in a seated position to 1250 W at age 20 (730 at age 70) during strenuous exercise. The corresponding rates for women are about 30 percent lower. Maximum metabolic rates of trained athletes can exceed 2000 W. We are interested in metabolic rate of the occupants of a building when we deal with heating and air conditioning because the metabolic rate represents the rate at which a body generates heat and dissipates it to the room. This body heat contributes to the heating in winter, but it adds to the cooling load of the building in summer.

1-116C The metabolic rate is proportional to the size of the body, and the metabolic rate of women, in general, is lower than that of men because of their smaller size. Clothing serves as insulation, and the thicker the clothing, the lower the environmental temperature that feels comfortable.

1-117C Asymmetric thermal radiation is caused by the *cold surfaces* of large windows, uninsulated walls, or cold products on one side, and the *warm surfaces* of gas or electric radiant heating panels on the walls or ceiling, solar heated masonry walls or ceilings on the other. Asymmetric radiation causes discomfort by exposing different sides of the body to surfaces at different temperatures and thus to different rates of heat loss or gain by radiation. A person whose left side is exposed to a cold window, for example, will feel like heat is being drained from that side of his or her body.

1-118C (*a*) Draft causes undesired local cooling of the human body by exposing parts of the body to high heat transfer coefficients. (*b*) Direct contact with *cold floor surfaces* causes localized discomfort in the feet by excessive heat loss by conduction, dropping the temperature of the bottom of the feet to uncomfortable levels.

1-119C Stratification is the formation of vertical still air layers in a room at difference temperatures, with highest temperatures occurring near the ceiling. It is likely to occur at places with high ceilings. It causes discomfort by exposing the head and the feet to different temperatures. This effect can be prevented or minimized by using destratification fans (ceiling fans running in reverse).

1-120C It is necessary to ventilate buildings to provide adequate fresh air and to get rid of excess carbon dioxide, contaminants, odors, and humidity. Ventilation increases the energy consumption for heating in winter by replacing the warm indoors air by the colder outdoors air. Ventilation also increases the energy consumption for cooling in summer by replacing the cold indoors air by the warm outdoors air. It is not a good idea to keep the bathroom fans on all the time since they will waste energy by expelling conditioned air (warm in winter and cool in summer) by the unconditioned outdoor air.
