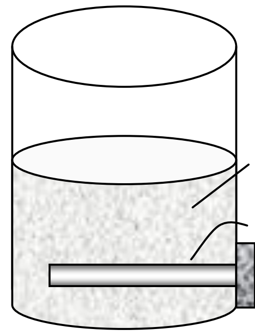
Review Problems

1-121 Cold water is to be heated in a 1200-W teapot. The time needed to heat the water is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Thermal properties of the teapot and the water are constant. **3** Heat loss from the teapot is negligible.

Properties The average specific heats are given to be 0.6 kJ/kg.°C for the teapot and 4.18 kJ/kg.°C for water.

Analysis We take the teapot and the water in it as our system that is a closed system (fixed mass). The energy balance in this case can be expressed as



$$E_{in} - E_{out} = \Delta E_{system}$$
$$E_{in} = \Delta U_{system} = \Delta U_{water} + \Delta U_{tea\ pot}$$

Then the amount of energy needed to raise the temperature of water and the teapot from 18°C to 96°C is

$$\begin{aligned} E_{in} &= (mC\Delta T)_{water} + (mC\Delta T)_{teapot} \\ &= (2.5\text{ kg})(4.18\text{ kJ / kg.}^\circ\text{C})(96-18)^\circ\text{C} + (0.8\text{ kg})(0.6\text{ kJ / kg.}^\circ\text{C})(96-18)^\circ\text{C} \\ &= 853\text{ kJ} \end{aligned}$$

The 1500 W electric heating unit will supply energy at a rate of 1.2 kW or 1.2 kJ per second. Therefore, the time needed for this heater to supply 853 kJ of heat is determined from

$$\Delta t = \frac{\text{Total energy transferred}}{\text{Rate of energy transfer}} = \frac{E_{in}}{\dot{E}_{transfer}} = \frac{853\text{ kJ}}{1.2\text{ kJ/s}} = 710\text{ s} = \mathbf{11.8\ min}$$

Discussion In reality, it will take longer to accomplish this heating process since some heat loss is inevitable during the heating process.

1-122 The duct of an air heating system of a house passes through an unheated space in the attic. The rate of heat loss from the air in the duct to the attic and its cost under steady conditions are to be determined.

Assumptions **1** Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -141°C and 3.77 MPa. **2** Steady operating conditions exist since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$. **3** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **4** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications.

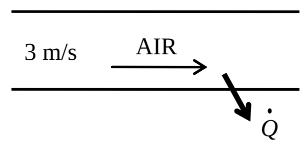
Properties The gas constant of air is R = 0.287 kJ/kg.K (Table A-1). The specific heat of air at room temperature is C_p = 1.007 kJ/kg·°C (Table A-15).

Analysis We take the heating duct as the system. This is a *control volume* since mass crosses the system boundary during the process. There is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Then the energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2 \quad \text{(since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0\text{)}$$

$$\dot{Q}_{\text{out}} = \dot{m}C_p(T_1 - T_2)$$



The density of air at the inlet conditions is determined from the ideal gas relation to be

$$\rho = \frac{P}{RT} = \frac{100 \text{ kPa}}{(0.287 \text{ kPa.m}^3/\text{kg.K})(65+273)\text{K}} = 1.031 \text{ kg/m}^3$$

The cross-sectional area of the duct is

$$A_c = \pi D^2/4 = \pi(0.20 \text{ m})^2/4 = 0.0314 \text{ m}^2$$

Then the mass flow rate of air through the duct and the rate of heat loss become

$$\dot{m} = \rho A_c \mathbf{V} = (1.031 \text{ kg/m}^3)(0.0314 \text{ m}^2)(3 \text{ m/s}) = 0.0971 \text{ kg/s}$$

and

$$\begin{aligned} \dot{Q}_{\text{loss}} &= \dot{m}C_p(T_{\text{in}} - T_{\text{out}}) \\ &= (0.0971 \text{kg/s})(1.007 \text{ kJ/kg.°C})(65-60)\text{°C} \\ &= \mathbf{0.489 kJ/s} \end{aligned}$$

or 1760 kJ/h. The cost of this heat loss to the home owner is

$$\begin{aligned} \text{Cost of Heat Loss} &= \frac{\text{(Rate of heat loss)(Unit cost of energy input)}}{\text{Furnace efficiency}} \\ &= \frac{(1760 \text{kJ/h})(\$0.58/\text{therm})}{0.82}\left(\frac{1 \text{ therm}}{105{,}500 \text{kJ}}\right) \\ &= \mathbf{\$0.012/h} \end{aligned}$$

Discussion The heat loss from the heating ducts in the attic is costing the homeowner 1.2 cents per hour. Assuming the heater operates 2,000 hours during a heating season, the annual cost of this heat loss adds up to $24. Most of this money can be saved by insulating the heating ducts in the unheated areas.

1-123

```
"GIVEN"
L=4 "[m]"
D=0.2 "[m]"
P_air_in=100 "[kPa]"
T_air_in=65 "[C]"
"Vel=3 [m/s], parameter to be varied"
T_air_out=60 "[C]"
eta_furnace=0.82
Cost_gas=0.58 "[$/therm]"

"PROPERTIES"
R=0.287 "[kJ/kg-K], gas constant of air"
C_p=CP(air, T=25) "at room temperature"

"ANALYSIS"
rho=P_air_in/(R*(T_air_in+273))
A_c=pi*D^2/4
m_dot=rho*A_c*Vel
Q_dot_loss=m_dot*C_p*(T_air_in-T_air_out)*Convert(kJ/s, kJ/h)
Cost_HeatLoss=Q_dot_loss/eta_furnace*Cost_gas*Convert(kJ, therm)*Convert($, cents)
```

Vel [m/s]	$Cost_{HeatLoss}$ [Cents/h]
1	0.3934
2	0.7868
3	1.18
4	1.574
5	1.967
6	2.361
7	2.754
8	3.147
9	3.541
10	3.934

1-124 Water is heated from 16°C to 43°C by an electric resistance heater placed in the water pipe as it flows through a showerhead steadily at a rate of 10 L/min. The electric power input to the heater, and the money that will be saved during a 10-min shower by installing a heat exchanger with an effectiveness of 0.50 are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time at any point within the system and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$,. **2** Water is an incompressible substance with constant specific heats. **3** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **4** Heat losses from the pipe are negligible.

Properties The density and specific heat of water at room temperature are ρ = 1 kg/L and C = 4.18 kJ/kg·°C (Table A-9).

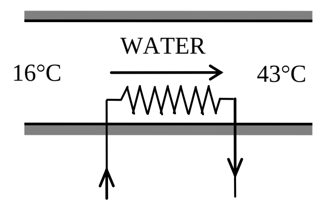
Analysis We take the pipe as the system. This is a *control volume* since mass crosses the system boundary during the process. We observe that there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Then the energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0\ (\text{steady})}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0 \quad \rightarrow \quad \dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{\text{e,in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{\text{e,in}} = \dot{m}(h_2 - h_1) = \dot{m}[C(T_2 - T_1) + v(P_2 - P_1)^{\nearrow 0}] = \dot{m}C(T_2 - T_1)$$

where



$$\dot{m} = \rho\dot{V} = (1\text{ kg/L})(10\text{ L/min}) = 10\text{ kg/min}$$

Substituting,

$$\dot{W}_{\text{e,in}} = (10/60\text{kg/s})(4.18\text{ kJ/kg}\cdot°\text{C})(43-16)°\text{C} = \mathbf{18.8\,kW}$$

The energy recovered by the heat exchanger is

$$\begin{aligned}\dot{Q}_{\text{saved}} &= \varepsilon\dot{Q}_{\max} = \varepsilon\dot{m}C(T_{\max} - T_{\min})\\ &= 0.5(10/60\text{ kg/s})(4.18\text{ kJ/kg.°C})(39-16)°\text{C}\\ &= 8.0\text{ kJ/s} = 8.0\text{ kW}\end{aligned}$$

Therefore, 8.0 kW less energy is needed in this case, and the required electric power in this case reduces to

$$\dot{W}_{\text{in,new}} = \dot{W}_{\text{in,old}} - \dot{Q}_{\text{saved}} = 18.8 - 8.0 = \mathbf{10.8\,kW}$$

The money saved during a 10-min shower as a result of installing this heat exchanger is

$$(8.0\text{ kW})(10/60\text{ h})(8.5\text{ cents/kWh}) = \mathbf{11.3\,cents}$$

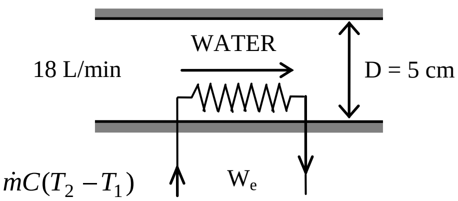
1-125 Water is to be heated steadily from 15°C to 50°C by an electrical resistor inside an insulated pipe. The power rating of the resistance heater and the average velocity of the water are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time at any point within the system and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$,. **2** Water is an incompressible substance with constant specific heats. **3** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **4** The pipe is insulated and thus the heat losses are negligible.

Properties The density and specific heat of water at room temperature are ρ = 1000 kg/m^3 and C = 4.18 kJ/kg·°C (Table A-9).

Analysis (*a*) We take the pipe as the system. This is a *control volume* since mass crosses the system boundary during the process. Also, there is only one inlet and one exit and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0\ (\text{steady})}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} = 0 \rightarrow \dot{E}_{in} = \dot{E}_{out}$$



$$\dot{W}_{e,in} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{e,in} = \dot{m}(h_2 - h_1) = \dot{m}[C(T_2 - T_1) + v(P_2 - P_1)^{\nearrow 0}] = \dot{m}C(T_2 - T_1)$$

The mass flow rate of water through the pipe is

$$\dot{m} = \rho \dot{V}_1 = (1000\ \text{kg/m}^3)(0.018\ \text{m}^3/\text{min}) = 18\ \text{kg/min}$$

Therefore,

$$\dot{W}_{e,in} = \dot{m}C(T_2 - T_1) = (18/60\ \text{kg/s})(4.18\ \text{kJ/kg}\cdot°\text{C})(50 - 15)°\text{C} = \mathbf{43.9\ kW}$$

(*b*) The average velocity of water through the pipe is determined from

$$\text{V}_1 = \frac{\dot{V}_1}{A_1} = \frac{\dot{V}}{\pi r^2} = \frac{0.018\ \text{m}^3/\text{min}}{\pi (0.025\ \text{m})^2} = \mathbf{9.17\ m/min}$$

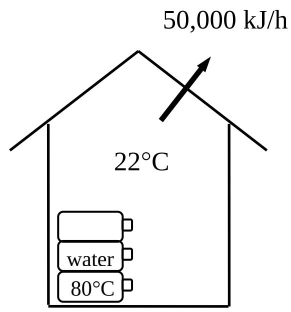
1-126 The heating of a passive solar house at night is to be assisted by solar heated water. The length of time that the electric heating system would run that night with or without solar heating are to be determined.

Assumptions **1** Water is an incompressible substance with constant specific heats. **2** The energy stored in the glass containers themselves is negligible relative to the energy stored in water. **3** The house is maintained at 22°C at all times.

Properties The density and specific heat of water at room temperature are ρ = 1 kg/L and *C* = 4.18 kJ/kg·°C (Table A-9).

Analysis (*a*) The total mass of water is

$$m_w = \rho V = (1\ \text{kg/L})(50 \times 20\ \text{L}) = 1000\ \text{kg}$$



Taking the contents of the house, including the water as our system, the energy balance relation can be written as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{e,in} - Q_{\text{out}} = \Delta U = (\Delta U)_{\text{water}} + (\Delta U)_{\text{air}}^{\nearrow 0}$$

$$\dot{W}_{e,in}\Delta t - Q_{out} = [mC(T_2 - T_1)]_{\text{water}}$$

Substituting,

$$(15\ \text{kJ/s})\Delta t - (50{,}000\ \text{kJ/h})(10\ \text{h}) = (1000\ \text{kg})(4.18\ \text{kJ/kg·°C})(22 - 80)\text{°C}$$

It gives

Δt = 17,170 s = **4.77 h**

(*b*) If the house incorporated no solar heating, the 1st law relation above would simplify further to

$$\dot{W}_{e,in}\Delta t - Q_{out} = 0$$

Substituting,

$$(15\ \text{kJ/s})\Delta t - (50{,}000\ \text{kJ/h})(10\ \text{h}) = 0$$

It gives

Δt = 33,330 s = **9.26 h**

1-127 A standing man is subjected to high winds and thus high convection coefficients. The rate of heat loss from this man by convection in still air at 20°C, in windy air, and the wind-chill factor are to be determined.

Assumptions **1** A standing man can be modeled as a 30-cm diameter, 170-cm long vertical cylinder with both the top and bottom surfaces insulated. **2** The exposed surface temperature of the person and the convection heat transfer coefficient is constant and uniform. **3** Heat loss by radiation is negligible.

Analysis The heat transfer surface area of the person is

$$A_s = \pi DL = \pi(0.3\text{ m})(1.70\text{ m}) = 1.60\text{ m}^2$$

Windy weather

The rate of heat loss from this man by convection in still air is

$$Q_{\text{still air}} = hA_s\Delta T = (15\text{ W/m}^2\cdot°\text{C})(1.60\text{ m}^2)(34 - 20)°\text{C} = \mathbf{336\text{ W}}$$

In windy air it would be

$$Q_{\text{windy air}} = hA_s\Delta T = (50\text{ W/m}^2\cdot°\text{C})(1.60\text{ m}^2)(34 - 20)°\text{C} = \mathbf{1120\text{ W}}$$

To lose heat at this rate in still air, the air temperature must be

$$1120\text{ W} = (hA_s\Delta T)_{\text{still air}} = (15\text{ W/m}^2\cdot°\text{C})(1.60\text{ m}^2)(34 - T_{\text{effective}})°\text{C}$$

which gives

$$T_{\text{effective}} = -12.7°\text{C}$$

That is, the windy air at 20°C feels as cold as still air at -12.7°C as a result of the wind-chill effect. Therefore, the wind-chill factor in this case is

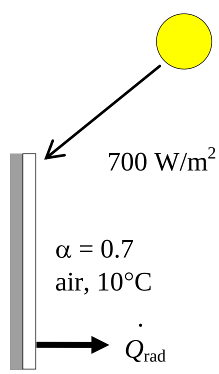
$$F_{\text{wind-chill}} = 20 - (-12.7) = \mathbf{32.7°C}$$

1-128 The backside of the thin metal plate is insulated and the front side is exposed to solar radiation. The surface temperature of the plate is to be determined when it stabilizes.

Assumptions **1** Steady operating conditions exist. **2** Heat transfer through the insulated side of the plate is negligible. **3** The heat transfer coefficient is constant and uniform over the plate. **4** Radiation heat transfer is negligible.

Properties The solar absorptivity of the plate is given to be $\alpha = 0.7$.

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



$$\dot{Q}_{\text{solarabsorbed}} = \dot{Q}_{\text{conv}}$$

$$\alpha\dot{Q}_{\text{solar}} = hA_s(T_s - T_o)$$

$$0.7\times A\times 700\text{W/m}^2 = (30\text{W/m}^2\cdot°\text{C})A_s(T_s - 10)$$

Canceling the surface area A_s and solving for T_s gives

$$T_s = \mathbf{26.3°C}$$

1-129 A room is to be heated by 1 ton of hot water contained in a tank placed in the room. The minimum initial temperature of the water is to be determined if it to meet the heating requirements of this room for a 24-h period.

Assumptions **1** Water is an incompressible substance with constant specific heats. **2** Air is an ideal gas with constant specific heats. **3** The energy stored in the container itself is negligible relative to the energy stored in water. **4** The room is maintained at 20°C at all times. **5** The hot water is to meet the heating requirements of this room for a 24-h period.

Properties The specific heat of water at room temperature is C = 4.18 kJ/kg·°C (Table A-9).

Analysis Heat loss from the room during a 24-h period is

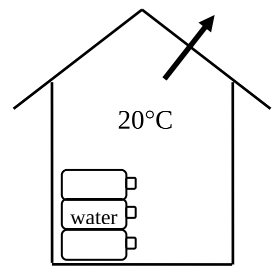
$$Q_{\text{loss}} = (10{,}000 \text{ kJ/h})(24 \text{ h}) = 240{,}000 \text{ kJ}$$

Taking the contents of the room, including the water, as our system, the energy balance can be written as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}} \rightarrow -Q_{\text{out}} = \Delta U = (\Delta U)_{\text{water}} + (\Delta U)_{\text{air}}^{\nearrow 0}$$

or

$$-Q_{\text{out}} = [mC(T_2 - T_1)]_{\text{water}}$$



Substituting,

$$-240{,}000 \text{ kJ} = (1000 \text{ kg})(4.18 \text{ kJ/kg·°C})(20 - T_1)$$

It gives

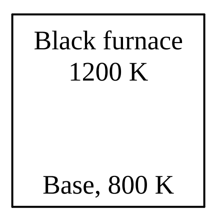
$$T_1 = \mathbf{77.4°C}$$

where T_1 is the temperature of the water when it is first brought into the room.

1-130 The base surface of a cubical furnace is surrounded by black surfaces at a specified temperature. The net rate of radiation heat transfer to the base surface from the top and side surfaces is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The top and side surfaces of the furnace closely approximate black surfaces. **3** The properties of the surfaces are constant.

Properties The emissivity of the base surface is ε = 0.7.



Analysis The base surface is completely surrounded by the top and side surfaces. Then using the radiation relation for a surface completely surrounded by another large (or black) surface, the net rate of radiation heat transfer from the top and side surfaces to the base is determined to be

$$\begin{aligned}\dot{Q}_{\text{rad,base}} &= \varepsilon A\sigma(T_{\text{base}}^4 - T_{\text{surr}}^4)\\ &= (0.7)(3\times 3\,\text{m}^2)(5.67\times 10^{-8}\text{ W/m}^2.\text{K}^4)[(1200\,\text{K})^4 - (800\,\text{K})^4]\\ &= \mathbf{594{,}400\,W}\end{aligned}$$

1-131 A refrigerator consumes 600 W of power when operating, and its motor remains on for 5 min and then off for 15 min periodically. The average thermal conductivity of the refrigerator walls and the annual cost of operating this refrigerator are to be determined.

Assumptions **1** Quasi-steady operating conditions exist. **2** The inner and outer surface temperatures of the refrigerator remain constant.

Analysis The total surface area of the refrigerator where heat transfer takes place is

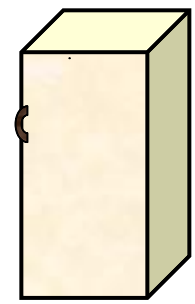
$$A_{\text{total}} = 2\left[(1.8\times1.2)+(1.8\times0.8)+(1.2\times0.8)\right] = 9.12\ \text{m}^2$$

Since the refrigerator has a COP of 2.5, the rate of heat removal from the refrigerated space, which is equal to the rate of heat gain in steady operation, is

$$\dot{Q} = \dot{W}_e \times \text{COP} = (600\ \text{W})\times 2.5 = 1500\ \text{W}$$

But the refrigerator operates a quarter of the time (5 min on, 15 min off). Therefore, the average rate of heat gain is

$$\dot{Q}_{\text{ave}} = \dot{Q}/4 = (1500\ \text{W})/4 = 375\ \text{W}$$



Then the thermal conductivity of refrigerator walls is determined to be

$$\dot{Q}_{\text{ave}} = kA\frac{\Delta T_{\text{ave}}}{L} \longrightarrow k = \frac{\dot{Q}_{\text{ave}}L}{A\Delta T_{\text{ave}}} = \frac{(375\ \text{W})(0.03\ \text{m})}{(9.12\ \text{m}^2)(17-6)^\circ\text{C}} = \mathbf{0.112\ W/m.^\circ C}$$

The total number of hours this refrigerator remains on per year is

$$\Delta t = 365\times24/4 = 2190\,\text{h}$$

Then the total amount of electricity consumed during a one-year period and the annular cost of operating this refrigerator are

$$\text{Annual Electricity Usage} = \dot{W}_e\Delta t = (0.6\ \text{kW})(2190\,\text{h/yr}) = 1314\,\text{kWh/yr}$$

$$\text{Annual cost} = (1314\,\text{kWh/yr})(\$0.08/\text{kWh}) = \mathbf{\$105.1/yr}$$

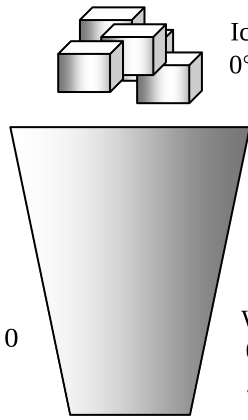
1-132 A 0.2-L glass of water at 20°C is to be cooled with ice to 5°C. The amounts of ice or cold water that needs to be added to the water are to be determined.

Assumptions **1** Thermal properties of the ice and water are constant. **2** Heat transfer to the water is negligible.

Properties The density of water is 1 kg/L, and the specific heat of water at room temperature is C = 4.18 kJ/kg·°C (Table A-9). The heat of fusion of ice at atmospheric pressure is 333.7 kJ/kg,.

Analysis The mass of the water is

$$m_w = \rho V = (1\text{kg/L})(0.2\,\text{L}) = 0.2\text{kg}$$



We take the ice and the water as our system, and disregard any heat and mass transfer. This is a reasonable assumption since the time period of the process is very short. Then the energy balance can be written as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}} \rightarrow 0 = \Delta U \rightarrow (\Delta U)_{\text{ice}} + (\Delta U)_{\text{water}} = 0$$

$$\left[mC(0^\circ\text{C} - T_1)_{\text{solid}} + mh_{if} + mC(T_2 - 0^\circ\text{C})_{\text{liquid}}\right]_{\text{ice}} + \left[mC(T_2 - T_1)\right]_{\text{water}} = 0$$

Noting that $T_{1,\,\text{ice}}$ = 0°C and T_2 = 5°C and substituting

m[0 + 333.7 kJ/kg + (4.18 kJ/kg·°C)(5-0)°C] + (0.2 kg)(4.18 kJ/kg·°C)(5-20)°C = 0

It gives m = 0.0354 kg = **35.4 g**

Cooling with cold water can be handled the same way. All we need to do is replace the terms for ice by the ones for cold water at 0°C:

$$(\Delta U)_{\text{coldwater}} + (\Delta U)_{\text{water}} = 0$$

$$\left[mC(T_2 - T_1)\right]_{\text{coldwater}} + \left[mC(T_2 - T_1)\right]_{\text{water}} = 0$$

Substituting,

[$m_{\text{cold water}}$ (4.18 kJ/kg·°C)(5 - 0)°C] + (0.2 kg)(4.18 kJ/kg·°C)(5-20)°C = 0

It gives m = 0.6 kg = **600 g**

Discussion Note that this is 17 times the amount of ice needed, and it explains why we use ice instead of water to cool drinks.

1-133

```
"GIVEN"
V=0.0002 "[m^3]"
T_w1=20 "[C]"
T_w2=5 "[C]"
"T_ice=0 [C], parameter to be varied"
T_melting=0 "[C]"

"PROPERTIES"
rho=density(water, T=25, P=101.3) "at room temperature"
C_w=CP(water, T=25, P=101.3) "at room temperature"
C_ice=c_('Ice', T_ice)
h_if=333.7 "[kJ/kg]"

"ANALYSIS"
m_w=rho*V
DELTAU_ice+DELTAU_w=0 "energy balance"
DELTAU_ice=m_ice*C_ice*(T_melting-T_ice)+m_ice*h_if
DELTAU_w=m_w*C_w*(T_w2-T_w1)
```

T_{ice} [C]	m_{ice} [kg]
-24	0.03291
-22	0.03323
-20	0.03355
-18	0.03389
-16	0.03424
-14	0.0346
-12	0.03497
-10	0.03536
-8	0.03575
-6	0.03616
-4	0.03658
-2	0.03702
0	0.03747

1-134E A 1-short ton (2000 lbm) of water at 70°F is to be cooled in a tank by pouring 160 lbm of ice at 25°F into it. The final equilibrium temperature in the tank is to be determined. The melting temperature and the heat of fusion of ice at atmospheric pressure are 32°F and 143.5 Btu/lbm, respectively

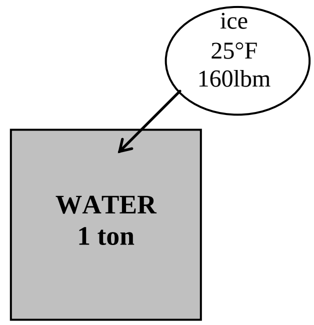
Assumptions **1** Thermal properties of the ice and water are constant. **2** Heat transfer to the water is negligible.

Properties The density of water is 62.4 lbm/ft^3, and the specific heat of water at room temperature is C = 1.0 Btu/lbm·°F (Table A-9). The heat of fusion of ice at atmospheric pressure is 143.5 Btu/lbm and the specific heat of ice is 0.5 Btu/lbm.°F.

Analysis We take the ice and the water as our system, and disregard any heat transfer between the system and the surroundings. Then the energy balance for this process can be written as

$$\underbrace{E_{in}-E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}} \to 0=\Delta U \to (\Delta U)_{\text{ice}}+(\Delta U)_{\text{water}}=0$$

$$\left[mC(32°\text{F}-T_1)_{\text{solid}}+mh_{if}+mC(T_2-32°\text{F})_{\text{liquid}}\right]_{\text{ice}}+\left[mC(T_2-T_1)\right]_{\text{water}}=0$$



Substituting,

$$(160\text{ lbm})[(0.50\text{ Btu/lbm}\cdot°\text{F})(32-25)°\text{F}+143.5\text{ Btu/lbm}+(1.0\text{ Btu/lbm}\cdot°\text{F})(T_2-32)°\text{F}]$$
$$+(2000\text{ lbm})(1.0\text{ Btu/lbm}\cdot°\text{F})(T_2-70)°\text{F}=0$$

It gives T_2 = **56.3°F**

which is the final equilibrium temperature in the tank.

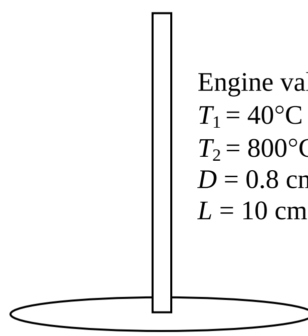
1-135 Engine valves are to be heated in a heat treatment section. The amount of heat transfer, the average rate of heat transfer, the average heat flux, and the number of valves that can be heat treated daily are to be determined.

Assumptions Constant properties given in the problem can be used.

Properties The average specific heat and density of valves are given to be C_p = 440 J/kg.°C and ρ = 7840 kg/m^3.

Analysis (*a*) The amount of heat transferred to the valve is simply the change in its internal energy, and is determined from

$$Q=\Delta U=mC_p(T_2-T_1)$$
$$=(0.0788\text{ kg})(0.440\text{ kJ/kg.°C})(800-40)°\text{C}=\mathbf{26.35\text{ kJ}}$$



(*b*) The average rate of heat transfer can be determined from

$$\dot{Q}_{\text{ave}}=\frac{Q}{\Delta t}=\frac{26.35\text{ kJ}}{5\times 60\text{ s}}=0.0878\text{ kW}=\mathbf{87.8\text{ W}}$$

(*c*) The average heat flux is determined from

$$\dot{q}_{\text{ave}}=\frac{\dot{Q}_{\text{ave}}}{A_s}=\frac{\dot{Q}_{\text{ave}}}{2\pi DL}=\frac{87.8\text{ W}}{2\pi(0.008\text{ m})(0.1\text{ m})}=\mathbf{1.75\times10^4\text{ W/m}^2}$$

(*d*) The number of valves that can be heat treated daily is

$$\text{Number of valves}=\frac{(10\times 60\text{ min})(25\text{ valves})}{(5\text{ min})}=\mathbf{3000\text{ valves}}$$

1-136 Somebody takes a shower using a mixture of hot and cold water. The mass flow rate of hot water and the average temperature of mixed water are to be determined.

Assumptions The hot water temperature changes from 80°C at the beginning of shower to 60°C at the end of shower. We use an average value of 70°C for the temperature of hot water exiting the tank.

Properties The properties of liquid water are C_p = 4.18 kJ/kg.°C and ρ = 977.6 kg/m³ (Table A-2).

Analysis We take the water tank as the system. The energy balance for this system can be expressed as

$$E_{in} - E_{out} = \Delta E_{sys}$$
$$\left[\dot{W}_{e,in} + \dot{m}_{hot} C(T_{in} - T_{out})\right]\Delta t = m_{tank} C(T_2 - T_1)$$

where T_{out} is the average temperature of hot water leaving the tank: (80+70)/2=70°C and

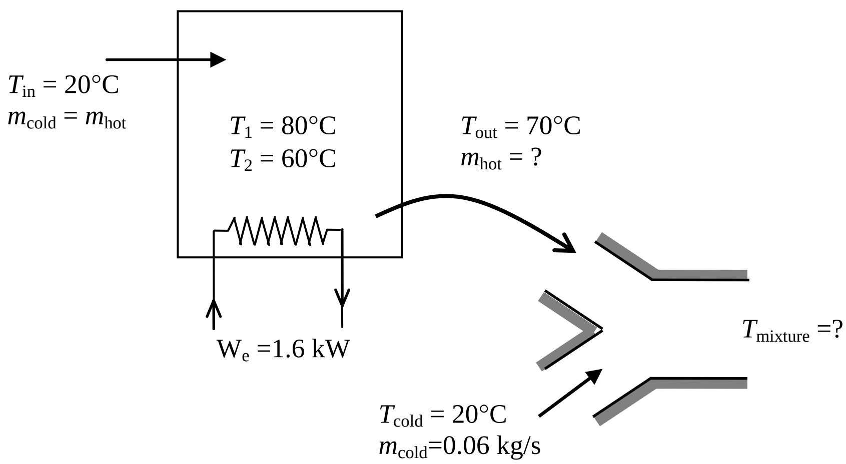
$$m_{tank} = \rho V = (977.6\ \text{kg/m}^3)(0.06\ \text{m}^3) = 58.656\ \text{kg}$$

Substituting,

$$\left[1.6\ \text{kJ/s} + \dot{m}_{hot}(4.18\text{kJ/kg.°C})(20-70)\text{°C}\right](8\times 60\ \text{s}) = (58.656\text{kg})(4.18\text{kJ/kg.°C})(60-80)\text{°C}$$
$$\dot{m}_{hot} = \mathbf{0.0565 kg/s}$$

To determine the average temperature of the mixture, an energy balance on the mixing section can be expressed as

$$\dot{E}_{in} = \dot{E}_{out}$$
$$\dot{m}_{hot} C T_{hot} + \dot{m}_{cold} C T_{cold} = (\dot{m}_{hot} + \dot{m}_{cold}) C T_{mixture}$$
$$(0.0565\text{kg/s})(4.18\ \text{kJ/kg.°C})(70\text{°C}) + (0.06\ \text{kg/s})(4.18\ \text{kJ/kg.°C})(20\text{°C}) = (0.0565 + 0.06\ \text{kg/s})(4.18\ \text{kJ/kg.°C})T_{mixture}$$
$$T_{mixture} = \mathbf{44.2°C}$$



1-137 The glass cover of a flat plate solar collector with specified inner and outer surface temperatures is considered. The fraction of heat lost from the glass cover by radiation is to be determined.

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

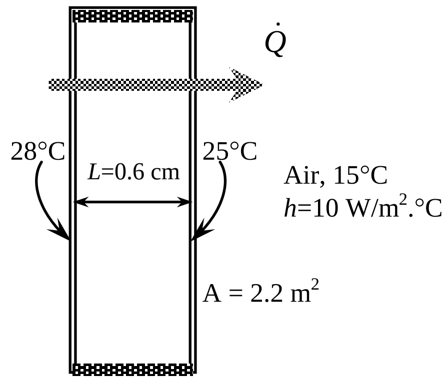
Properties The thermal conductivity of the glass is given to be k = 0.7 W/m·°C.

Analysis Under steady conditions, the rate of heat transfer through the glass by conduction is

$$\dot{Q}_{\text{cond}} = kA\frac{\Delta T}{L} = (0.7\ \text{W/m}\cdot{}^\circ\text{C})(2.2\ \text{m}^2)\frac{(28-25)^\circ\text{C}}{0.006\ \text{m}} = 770\ \text{W}$$

The rate of heat transfer from the glass by convection is

$$\dot{Q}_{\text{conv}} = hA\Delta T = (10\ \text{W/m}^2\cdot{}^\circ\text{C})(2.2\ \text{m}^2)(25-15)^\circ\text{C} = 220\ \text{W}$$



Under steady conditions, the heat transferred through the cover by conduction should be transferred from the outer surface by convection and radiation. That is,

$$\dot{Q}_{\text{rad}} = \dot{Q}_{\text{cond}} - \dot{Q}_{\text{conv}} = 770 - 220 = 550\ \text{W}$$

Then the fraction of heat transferred by radiation becomes

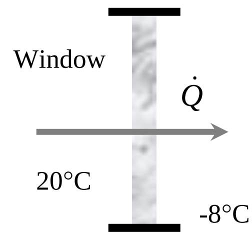
$$f = \frac{\dot{Q}_{\text{rad}}}{\dot{Q}_{\text{cond}}} = \frac{550}{770} = \mathbf{0.714} \quad \text{(or 71.4\%)}$$

1-138 The range of U-factors for windows are given. The range for the rate of heat loss through the window of a house is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat losses associated with the infiltration of air through the cracks/openings are not considered.

Analysis The rate of heat transfer through the window can be determined from

$$\dot{Q}_{\text{window}} = U_{\text{overall}} A_{\text{window}} (T_{in} - T_{out})$$



where T_i and T_o are the indoor and outdoor air temperatures, respectively, U_{overall} is the U-factor (the overall heat transfer coefficient) of the window, and A_{window} is the window area. Substituting,

Maximum heat loss: $$\dot{Q}_{\text{window,max}} = (6.25\ \text{W/m}^2\cdot°\text{C})(1.2\times1.8\ \text{m}^2)[20-(-8)]°\text{C} = \mathbf{378\ W}$$

Minimum heat loss: $$\dot{Q}_{\text{window,min}} = (1.25\ \text{W/m}^2\cdot°\text{C})(1.2\times1.8\ \text{m}^2)[20-(-8)]°\text{C} = \mathbf{76\ W}$$

Discussion Note that the rate of heat loss through windows of identical size may differ by a factor of 5, depending on how the windows are constructed.

1-139

```
"GIVEN"
A=1.2*1.8 "[m^2]"
T_1=20 "[C]"
T_2=-8 "[C]"
"U=1.25 [W/m^2-C], parameter to be varied"

"ANALYSIS"
Q_dot_window=U*A*(T_1-T_2)
```

U [W/m^2.C]	Q_{window} [W]
1.25	75.6
1.75	105.8
2.25	136.1
2.75	166.3
3.25	196.6
3.75	226.8
4.25	257
4.75	287.3
5.25	317.5
5.75	347.8
6.25	378

1-140 . . . 1-144 Design and Essay Problems