## Review Problems

4-110 Heat is transferred to a piston-cylinder device containing air. The expansion work is to be determined.

Assumptions **1** There is no friction between piston and cylinder. **2** Air is an ideal gas.

Properties The gas contant for air is 0.287 kJ/kg.K (Table A-2a).

Analysis Noting that the gas constant represents the boundary work for a unit mass and a unit temperature change, the expansion work is simply determined from

$$W_b = m\Delta TR = (0.5\,\text{kg})(5\,\text{K})(0.287\,\text{kJ/kg.K}) = \textbf{0.7175 kJ}$$

Air
0.5 kg
$\Delta T=5°C$

Q
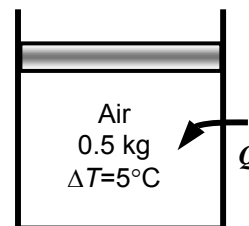
4-111 Solar energy is to be stored as sensible heat using phase-change materials, granite rocks, and water. The amount of heat that can be stored in a 5-m^3 = 5000 L space using these materials as the storage medium is to be determined.

Assumptions **1** The materials have constant properties at the specified values. **2** No allowance is made for voids, and thus the values calculated are the upper limits.

Analysis The amount of energy stored in a medium is simply equal to the increase in its internal energy, which, for incompressible substances, can be determined from $\Delta U = mc(T_2 - T_1)$.

(*a*) The latent heat of glaubers salts is given to be 329 kJ/L. Disregarding the sensible heat storage in this case, the amount of energy stored is becomes

$$\Delta U_{\text{salt}} = mh_{if} = (5000\,\text{L})(329\,\text{kJ/L}) = \textbf{1,645,000 kJ}$$

This value would be even larger if the sensible heat storage due to temperature rise is considered.

(*b*) The density of granite is 2700 kg/m^3 (Table A-3), and its specific heat is given to be c = 2.32 kJ/kg.°C. Then the amount of energy that can be stored in the rocks when the temperature rises by 20°C becomes

$$\Delta U_{\text{rock}} = \rho V c \Delta T = (2700\,\text{kg/m}^3)(5\,\text{m}^3)(2.32\,\text{kJ/kg.°C})(20°C) = \textbf{626,400 kJ}$$

(*c*) The density of water is about 1000 kg/m^3 (Table A-3), and its specific heat is given to be c = 4.0 kJ/kg.°C. Then the amount of energy that can be stored in the water when the temperature rises by 20°C becomes

$$\Delta U_{\text{rock}} = \rho V c \Delta T = (1000\,\text{kg/m}^3)(5\,\text{m}^3)(4.0\,\text{kJ/kg.°C})(20°C) = \textbf{400,00 kJ}$$

Discussion Note that the greatest amount of heat can be stored in phase-change materials essentially at constant temperature. Such materials are not without problems, however, and thus they are not widely used.

4-112 The ideal gas in a piston-cylinder device is cooled at constant pressure. The gas constant and the molar mass of this gas are to be determined.

Assumptions There is no friction between piston and cylinder.

Properties The specific heat ratio is given to be 1.667

Analysis Noting that the gas constant represents the boundary work for a unit mass and a unit temperature change, the gas constant is simply determined from

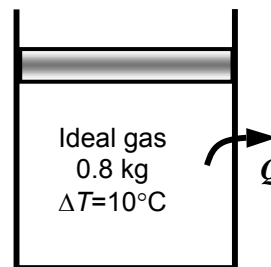$$R = \frac{W_b}{m\Delta T} = \frac{16.6 \text{ kJ}}{(0.8 \text{ kg})(10 \text{ °C})} = \textbf{2.075 kJ/kg.K}$$

The molar mass of the gas is

$$M = \frac{R_u}{R} = \frac{8.314 \text{ kJ/kmol.K}}{2.075 \text{ kJ/kg.K}} = \textbf{4.007 kg/kmol}$$

The specific heats are determined as

$$c_v = \frac{R}{k-1} = \frac{2.075 \text{ kJ/kg.K}}{1.667-1} = \textbf{3.111 kJ/kg.°C}$$

$$c_p = c_v + R = 3.111 \text{ kJ/kg.K} + 2.075 \text{ kJ/kg.K} = \textbf{5.186 kJ/kg.°C}$$

4-113 For a 10°C temperature change of air, the final velocity and final elevation of air are to be determined so that the internal, kinetic and potential energy changes are equal.

*Properties* The constant-volume specific heat of air at room temperature is 0.718 kJ/kg.°C (Table A-2).

Analysis The internal energy change is determined from

$$\Delta u = c_v \Delta T = (0.718 \text{ kJ/kg.°C})(10\text{°C}) = 7.18 \text{ kJ/kg}$$

Equating kinetic and potential energy changes to internal energy change, the final velocity and elevation are determined from

$$\Delta u = \Delta ke = \frac{1}{2}(V_2^2 - V_1^2) \longrightarrow 7.18 \text{ kJ/kg} = \frac{1}{2}(V_2^2 - 0 \text{ m}^2/\text{s}^2)\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) \longrightarrow V_2 = \textbf{119.8 m/s}$$

$$\Delta u = \Delta pe = g(z_2 - z_1) \longrightarrow 7.18 \text{ kJ/kg} = (9.81 \text{ m/s}^2)(z_2 - 0 \text{ m})\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) \longrightarrow z_2 = \textbf{731.9 m}$$
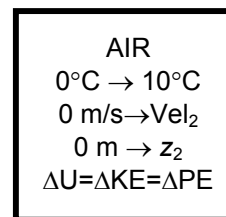
4-114 A cylinder equipped with an external spring is initially filled with air at a specified state. Heat is transferred to the air, and both the temperature and pressure rise. The total boundary work done by the air, and the amount of work done against the spring are to be determined, and the process is to be shown on a $P\text{-}v$ diagram.

Assumptions **1** The process is quasi-equilibrium. **2** The spring is a linear spring.

Analysis (*a*) The pressure of the gas changes linearly with volume during this process, and thus the process curve on a $P\text{-}V$ diagram will be a straight line. Then the boundary work during this process is simply the area under the process curve, which is a trapezoidal. Thus,
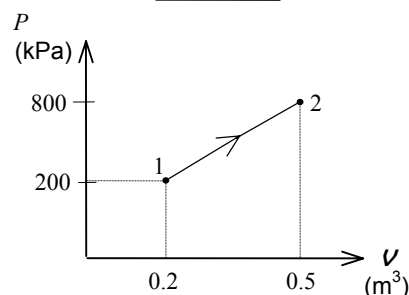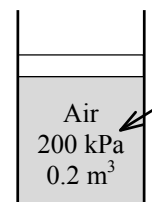
$$W_{b,out} = \text{Area} = \frac{P_1 + P_2}{2}(V_2 - V_1)$$

$$= \frac{(200 + 800)\text{kPa}}{2}(0.5 - 0.2)\text{m}^3\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right)$$

$$= \mathbf{150\ kJ}$$

(*b*) If there were no spring, we would have a constant pressure process at P = 200 kPa. The work done during this process is

$$W_{b,out,no\ spring} = \int_1^2 P dV = P(V_2 - V_1)$$

$$= (200\text{ kPa})(0.5 - 0.2)\text{m}^3/\text{kg}\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) = 60\text{ kJ}$$

Thus,

$$W_{spring} = W_b - W_{b,no\ spring} = 150 - 60 = \mathbf{90\ kJ}$$

4-115 A cylinder equipped with a set of stops for the piston is initially filled with saturated liquid-vapor mixture of water a specified pressure. Heat is transferred to the water until the volume increases by 20%. The initial and final temperature, the mass of the liquid when the piston starts moving, and the work done during the process are to be determined, and the process is to be shown on a P-v diagram.

Assumptions The process is quasi-equilibrium.

Analysis (*a*) Initially the system is a saturated mixture at 125 kPa pressure, and thus the initial temperature is

$$T_1 = T_{sat@125\ kPa} = \textbf{106.0°C}$$

The total initial volume is

$$V_1 = m_f v_f + m_g v_g = 2 \times 0.001048 + 3 \times 1.3750 = 4.127\ m^3$$

Then the total and specific volumes at the final state are

$$V_3 = 1.2V_1 = 1.2 \times 4.127 = 4.953\ m^3$$

$$v_3 = \frac{V_3}{m} = \frac{4.953\ m^3}{5\ kg} = 0.9905\ m^3/kg$$

Thus,

$$\left.\begin{array}{l} P_3 = 300\ kPa \\ v_3 = 0.9905\ m^3/kg \end{array}\right\} T_3 = \textbf{373.6°C}$$

(*b*) When the piston first starts moving, $P_2 = 300$ kPa and $V_2 = V_1 = 4.127\ m^3$. The specific volume at this state is

$$v_2 = \frac{V_2}{m} = \frac{4.127\ m^3}{5\ kg} = 0.8254\ m^3/kg$$

which is greater than $v_g = 0.60582\ m^3/kg$ at 300 kPa. Thus **no liquid** is left in the cylinder when the piston starts moving.

(*c*) No work is done during process 1-2 since $V_1 = V_2$. The pressure remains constant during process 2-3 and the work done during this process is

$$W_b = \int_2^3 P\,dV = P_2(V_3 - V_2) = (300\ kPa)(4.953 - 4.127)m^3 \left(\frac{1\ kJ}{1\ kPa \cdot m^3}\right) = \textbf{247.6 kJ}$$
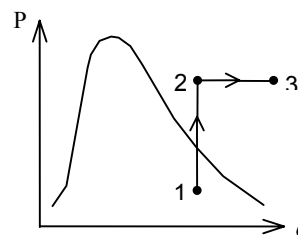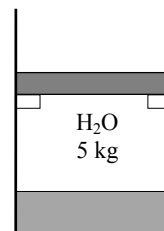
4-116E A spherical balloon is initially filled with air at a specified state. The pressure inside is proportional to the square of the diameter. Heat is transferred to the air until the volume doubles. The work done is to be determined.

Assumptions **1** Air is an ideal gas. **2** The process is quasi-equilibrium.

Properties The gas constant of air is $R = 0.06855$ Btu/lbm.R (Table A-1E).

Analysis The dependence of pressure on volume can be expressed as

$$V = \frac{1}{6}\pi D^3 \longrightarrow D = \left(\frac{6V}{\pi}\right)^{1/3}$$

$$P \propto D^2 \longrightarrow P = kD^2 = k\left(\frac{6V}{\pi}\right)^{2/3}$$

or, $k\left(\frac{6}{\pi}\right)^{2/3} = P_1 V_1^{-2/3} = P_2 V_2^{-2/3}$

Also, $\dfrac{P_2}{P_1} = \left(\dfrac{V_2}{V_1}\right)^{2/3} = 2^{2/3} = 1.587$

and $\dfrac{P_1 V_1}{T_1} = \dfrac{P_2 V_2}{T_2} \longrightarrow T_2 = \dfrac{P_2 V_2}{P_1 V_1} T_1 = 1.587 \times 2 \times (800\text{ R}) = 2539\text{ R}$

Thus,

$$W_b = \int_1^2 P\,dV = \int_1^2 k\left(\frac{6V}{\pi}\right)^{2/3} dV = \frac{3k}{5}\left(\frac{6}{\pi}\right)^{2/3}\left(V_2^{5/3} - V_1^{5/3}\right) = \frac{3}{5}(P_2 V_2 - P_1 V_1)$$

$$= \frac{3}{5}mR(T_2 - T_1) = \frac{3}{5}(10\text{ lbm})(0.06855\text{ Btu/lbm}\cdot\text{R})(2539 - 800)\text{R} = \textbf{715 Btu}$$

AIR
10 lbm
30 psia
800 R
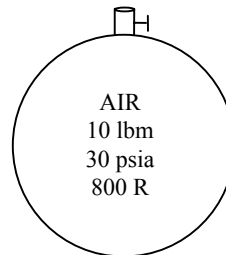
4-117E EES Problem 4-116E is reconsidered. Using the integration feature, the work done is to be determined and compared to the 'hand calculated' result.

Analysis The problem is solved using EES, and the solution is given below.

N=2
m=10"[lbm]"
P_1=30"[psia]"
T_1=800"[R]"
V_2=2*V_1
R=1545"[ft-lbf/lbmol-R]"/molarmass(air)"[ft-lbf/lbm-R]"
P_1*Convert(psia,lbf/ft^2)*V_1=m*R*T_1
V_1=4*pi*(D_1/2)^3/3"[ft^3]"
C=P_1/D_1^N
(D_1/D_2)^3=V_1/V_2
P_2=C*D_2^N"[psia]"
P_2*Convert(psia,lbf/ft^2)*V_2=m*R*T_2
P=C*D^N*Convert(psia,lbf/ft^2)"[ft^2]"
V=4*pi*(D/2)^3/3"[ft^3]"
W_boundary_EES=integral(P,V,V_1,V_2)*convert(ft-lbf,Btu)"[Btu]"
W_boundary_HAND=pi*C/(2*(N+3))*(D_2^(N+3)-D_1^(N+3))*convert(ft-lbf,Btu)*convert(ft^2,in^2)"[Btu]"

N	$W_{boundary}$ [Btu]
0	548.3
0.3333	572.5
0.6667	598.1
1	625
1.333	653.5
1.667	683.7
2	715.5
2.333	749.2
2.667	784.8
3	822.5
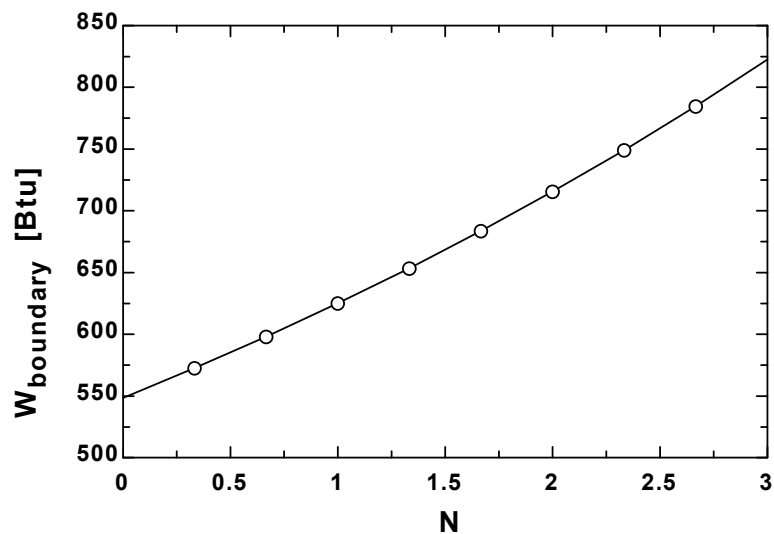
4-118 A cylinder is initially filled with saturated R-134a vapor at a specified pressure. The refrigerant is heated both electrically and by heat transfer at constant pressure for 6 min. The electric current is to be determined, and the process is to be shown on a T-v diagram.

Assumptions **1** The cylinder is stationary and thus the kinetic and potential energy changes are negligible. **2** The thermal energy stored in the cylinder itself and the wires is negligible. **3** The compression or expansion process is quasi-equilibrium.

Analysis We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this stationary closed system can be expressed as

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

$$Q_{in} + W_{e,in} - W_{b,out} = \Delta U \quad (\text{since } Q = \text{KE} = \text{PE} = 0)$$

$$Q_{in} + W_{e,in} = m(h_2 - h_1)$$

$$Q_{in} + (VI\Delta t) = m(h_2 - h_1)$$

since $\Delta U + W_b = \Delta H$ during a constant pressure quasi-equilibrium process. The properties of R-134a are (Tables A-11 through A-13)

$$\left. \begin{array}{l} P_1 = 240 \text{ kPa} \\ \text{sat. vapor} \end{array} \right\} h_1 = h_{g@240kPa} = 247.28 \text{ kJ/kg}$$

$$\left. \begin{array}{l} P_2 = 240 \text{ kPa} \\ T_1 = 70°C \end{array} \right\} h_2 = 314.51 \text{ kJ/kg}$$

Substituting,

$$300{,}000 \text{ VA} + (110 \text{ V})(I)(6 \times 60 \text{ s}) = (12 \text{ kg})(314.51 - 247.28)\text{kJ/kg}\left(\frac{1000 \text{ VA}}{1 \text{ kJ/s}}\right)$$

$$I = \textbf{12.8 A}$$
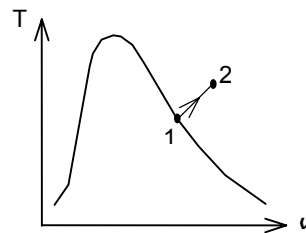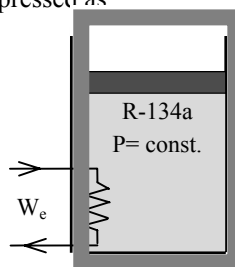
4-119 A cylinder is initially filled with saturated liquid-vapor mixture of R-134a at a specified pressure. Heat is transferred to the cylinder until the refrigerant vaporizes completely at constant pressure. The initial volume, the work done, and the total heat transfer are to be determined, and the process is to be shown on a P-v diagram.

Assumptions **1** The cylinder is stationary and thus the kinetic and potential energy changes are negligible. **2** The thermal energy stored in the cylinder itself is negligible. **3** The compression or expansion process is quasi-equilibrium.

Analysis (*a*) Using property data from R-134a tables (Tables A-11 through A-13), the initial volume of the refrigerant is determined to be

$$P_1 = 200 \text{ kPa} \left.\begin{array}{l} v_f = 0.0007533, \quad v_g = 0.099867 \text{ m}^3/\text{kg} \\ u_f = 38.28, \quad\quad u_{fg} = 186.21 \text{ kJ/kg} \end{array}\right\}$$
$$x_1 = 0.25$$

R-134a
200 kPa

Q

$$v_1 = v_f + x_1 v_{fg} = 0.0007533 + 0.25 \times (0.099867 - 0.0007533) = 0.02553 \text{ m}^3/\text{kg}$$
$$u_1 = u_f + x_1 u_{fg} = 38.28 + 0.25 \times 186.21 = 84.83 \text{ kJ/kg}$$

$$V_1 = m v_1 = (0.2 \text{ kg})(0.02553 \text{ m}^3/\text{kg}) = \textbf{0.005106 m}^3$$

(*b*) The work done during this constant pressure process is

$$P_2 = 200 \text{ kPa} \left.\begin{array}{l} v_2 = v_{g@200 \text{ kPa}} = 0.09987 \text{ m}^3/\text{kg} \\ u_2 = u_{g@200 \text{ kPa}} = 224.48 \text{ kJ/kg} \end{array}\right\}$$
sat. vapor

$$W_{b,\text{out}} = \int_1^2 P d V = P(V_2 - V_1) = mP(v_2 - v_1)$$

$$= (0.2 \text{ kg})(200 \text{ kPa})(0.09987 - 0.02553)\text{m}^3/\text{kg}\left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right)$$

$$= \textbf{2.97 kJ}$$

(*c*) We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this stationary closed system can be expressed as

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

$$Q_{\text{in}} - W_{b,\text{out}} = \Delta U$$

$$Q_{\text{in}} = m(u_2 - u_1) + W_{b,\text{out}}$$

Substituting,

$$Q_{\text{in}} = (0.2 \text{ kg})(224.48 - 84.83)\text{kJ/kg} + 2.97 = \textbf{30.9 kJ}$$
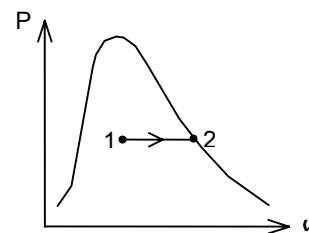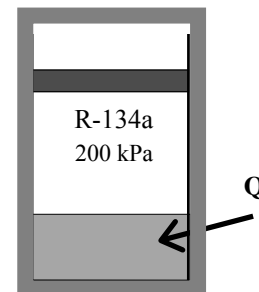
4-120 A cylinder is initially filled with helium gas at a specified state. Helium is compressed polytropically to a specified temperature and pressure. The heat transfer during the process is to be determined.

Assumptions **1** Helium is an ideal gas with constant specific heats. **2** The cylinder is stationary and thus the kinetic and potential energy changes are negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The compression or expansion process is quasi-equilibrium.

Properties The gas constant of helium is $R = 2.0769$ kPa.m^3/kg.K (Table A-1). Also, $c_v = 3.1156$ kJ/kg.K (Table A-2).

Analysis The mass of helium and the exponent n are determined to be

$$m = \frac{P_1 V_1}{RT_1} = \frac{(150 \text{ kPa})(0.5 \text{ m}^3)}{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})} = 0.123 \text{ kg}$$

$$\frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{RT_2} \longrightarrow V_2 = \frac{T_2 P_1}{T_1 P_2} V_1 = \frac{413 \text{ K}}{293 \text{ K}} \times \frac{150 \text{ kPa}}{400 \text{ kPa}} \times 0.5 \text{ m}^3 = 0.264 \text{ m}^3$$

$$P_2 V_2^n = P_1 V_1^n \longrightarrow \left(\frac{P_2}{P_1}\right) = \left(\frac{V_1}{V_2}\right)^n \longrightarrow \frac{400}{150} = \left(\frac{0.5}{0.264}\right)^n \longrightarrow n = 1.536$$

Then the boundary work for this polytropic process can be determined from

$$W_{b,in} = -\int_1^2 P dV = -\frac{P_2 V_2 - P_1 V_1}{1-n} = -\frac{mR(T_2 - T_1)}{1-n}$$

$$= -\frac{(0.123 \text{ kg})(2.0769 \text{ kJ/kg} \cdot \text{K})(413 - 293)\text{K}}{1 - 1.536} = 57.2 \text{ kJ}$$

We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. Taking the direction of heat transfer to be to the cylinder, the energy balance for this stationary closed system can be expressed as

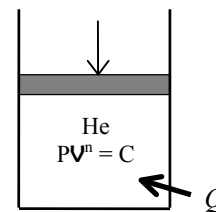$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$Q_{in} + W_{b,in} = \Delta U = m(u_2 - u_1)$$

$$Q_{in} = m(u_2 - u_1) - W_{b,in}$$

$$= mc_v(T_2 - T_1) - W_{b,in}$$

Substituting,

$$Q_{in} = (0.123 \text{ kg})(3.1156 \text{ kJ/kg·K})(413 - 293)\text{K} - (57.2 \text{ kJ}) = \textbf{-11.2 kJ}$$

The negative sign indicates that heat is lost from the system.

4-121 A cylinder and a rigid tank initially contain the same amount of an ideal gas at the same state. The temperature of both systems is to be raised by the same amount. The amount of extra heat that must be transferred to the cylinder is to be determined.

Analysis In the absence of any work interactions, other than the boundary work, the ΔH and ΔU represent the heat transfer for ideal gases for constant pressure and constant volume processes, respectively. Thus the extra heat that must be supplied to the air maintained at constant pressure is

$$Q_{in,\,extra} = \Delta H - \Delta U = mc_p \Delta T - mc_v \Delta T = m(c_p - c_v)\Delta T = mR\Delta T$$

where $\quad R = \dfrac{R_u}{M} = \dfrac{8.314 \text{ kJ/kmol} \cdot \text{K}}{25 \text{ kg/kmol}} = 0.3326 \text{ kJ/kg} \cdot \text{K}$

Substituting,

$$Q_{in,\,extra} = (12 \text{ kg})(0.3326 \text{ kJ/kg·K})(15 \text{ K}) = \textbf{59.9 kJ}$$
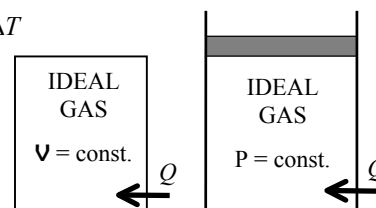
4-122 The heating of a passive solar house at night is to be assisted by solar heated water. The length of time that the electric heating system would run that night with or without solar heating are to be determined.

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-3).

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

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

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

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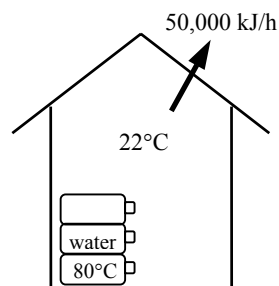
or, $\quad \dot{W}_{e,\text{in}}\Delta t - Q_{\text{out}} = [mc(T_2 - T_1)]_{\text{water}}$

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 $\quad \Delta t = 17{,}170\ \text{s} = \textbf{4.77 h}$

(b) If the house incorporated no solar heating, the energy balance relation above would simplify further to

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

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

It gives $\quad \Delta t = 33{,}333\ \text{s} = \textbf{9.26 h}$

4-123 An electric resistance heater is immersed in water. The time it will take for the electric heater to raise the water temperature to a specified temperature is to be determined.

Assumptions **1** Water is an incompressible substance with constant specific heats. **2** The energy stored in the container itself and the heater is negligible. **3** Heat loss from the container is 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-3).

Analysis Taking the water in the container as the system, the energy balance can be expressed as

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

$$W_{e,\text{in}} = (\Delta U)_{\text{water}}$$

$$\dot{W}_{e,\text{in}}\Delta t = mc(T_2 - T_1)_{\text{water}}$$

Substituting,

$$(1800\ \text{J/s})\Delta t = (40\ \text{kg})(4180\ \text{J/kg·°C})(80 - 20)°\text{C}$$

Solving for Δt gives

$$\Delta t = \textbf{5573 s = 92.9 min = 1.55 h}$$

4-74
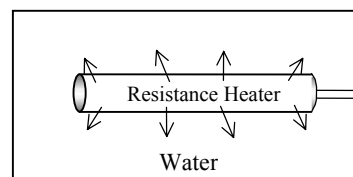
4-124 One ton of liquid water at 80°C is brought into a room. The final equilibrium temperature in the room is to be determined.

Assumptions **1** The room is well insulated and well sealed. **2** The thermal properties of water and air are constant.

Properties The gas constant of air is $R = 0.287$ kPa.m³/kg.K (Table A-1). The specific heat of water at room temperature is $c = 4.18$ kJ/kg·°C (Table A-3).

Analysis The volume and the mass of the air in the room are

$$V = 4 \times 5 \times 6 = 120 \text{ m}^3$$

$$m_{\text{air}} = \frac{P_1 V_1}{R T_1} = \frac{(100 \text{ kPa})(120 \text{ m}^3)}{(0.2870 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(295 \text{ K})} = 141.7 \text{ kg}$$

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

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}} \longrightarrow 0 = \Delta U = (\Delta U)_{\text{water}} + (\Delta U)_{\text{air}}$$
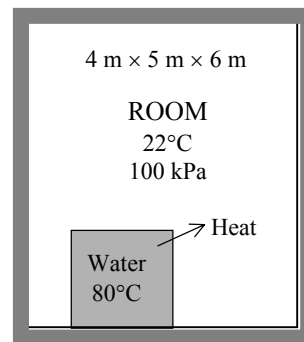
or $\quad [mc(T_2 - T_1)]_{\text{water}} + [mc_v(T_2 - T_1)]_{\text{air}} = 0$

Substituting,

$$(1000 \text{ kg})(4.180 \text{ kJ/kg} \cdot {}^\circ\text{C})(T_f - 80){}^\circ\text{C} + (141.7 \text{ kg})(0.718 \text{ kJ/kg} \cdot {}^\circ\text{C})(T_f - 22){}^\circ\text{C} = 0$$

It gives $\qquad T_f = \textbf{78.6°C}$

where T_f is the final equilibrium temperature in the room.

4 m × 5 m × 6 m

ROOM
22°C
100 kPa

Heat

Water
80°C

4-125 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-3).

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

$$Q_{\text{loss}} = (8000 \text{ kJ/h})(24 \text{ h}) = 192,000 \text{ kJ}$$

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

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}} \longrightarrow -Q_{\text{out}} = \Delta U = (\Delta U)_{\text{water}} + (\Delta U)_{\text{air}}^{\nearrow 0}$$
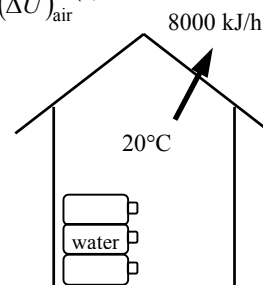
or $\quad -Q_{\text{out}} = [mc(T_2 - T_1)]_{\text{water}}$

Substituting,

$$-192,000 \text{ kJ} = (1000 \text{ kg})(4.18 \text{ kJ/kg} \cdot {}^\circ\text{C})(20 - T_1)$$

It gives $\quad T_1 = \textbf{65.9°C}$

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

8000 kJ/h

20°C

water

4-126 A sample of a food is burned in a bomb calorimeter, and the water temperature rises by 3.2°C when equilibrium is established. The energy content of the food is to be determined.

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 reaction chamber is negligible relative to the energy stored in water. **4** The energy supplied by the mixer is negligible.

Properties The specific heat of water at room temperature is $c = 4.18$ kJ/kg·°C (Table A-3). The constant volume specific heat of air at room temperature is $c_v = 0.718$ kJ/kg·°C (Table A-2).

Analysis The chemical energy released during the combustion of the sample is transferred to the water as heat. Therefore, disregarding the change in the sensible energy of the reaction chamber, the energy content of the food is simply the heat transferred to the water. Taking the water as our system, the energy balance can be written as
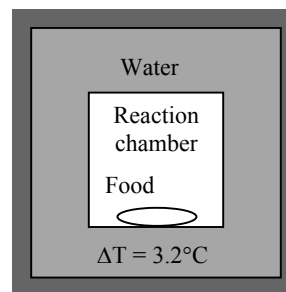
$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}} \rightarrow Q_{in} = \Delta U$$

or
$$Q_{in} = (\Delta U)_{water} = [mc(T_2 - T_1)]_{water}$$

Substituting, $Q_{in} = (3 \text{ kg})(4.18 \text{ kJ/kg·°C})(3.2°C) = 40.13$ kJ

for a 2-g sample. Then the energy content of the food per unit mass is

$$\frac{40.13 \text{ kJ}}{2 \text{ g}} \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) = \mathbf{20{,}060 \ kJ/kg}$$

Water

Reaction chamber

Food

$\Delta T = 3.2°C$

To make a rough estimate of the error involved in neglecting the thermal energy stored in the reaction chamber, we treat the entire mass within the chamber as air and determine the change in sensible internal energy:

$$(\Delta U)_{chamber} = [mc_v(T_2 - T_1)]_{chamber} = (0.102 \text{ kg})(0.718 \text{ kJ/kg·°C})(3.2°C) = 0.23 \text{ kJ}$$

which is less than 1% of the internal energy change of water. Therefore, it is reasonable to disregard the change in the sensible energy content of the reaction chamber in the analysis.

4-127 A man drinks one liter of cold water at 3°C in an effort to cool down. The drop in the average body temperature of the person under the influence of this cold water is to be determined.

Assumptions 1 Thermal properties of the body and water are constant. **2** The effect of metabolic heat generation and the heat loss from the body during that time period are negligible.

Properties The density of water is very nearly 1 kg/L, and the specific heat of water at room temperature is $C = 4.18$ kJ/kg·°C (Table A-3). The average specific heat of human body is given to be 3.6 kJ/kg.°C.

Analysis. The mass of the water is
$$m_w = \rho V = (1 \text{ kg/L})(1 \text{ L}) = 1 \text{ kg}$$

We take the man and the water as our system, and disregard any heat and mass transfer and chemical reactions. Of course these assumptions may be acceptable only for very short time periods, such as the time it takes to drink the water. Then the energy balance can be written as

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

$$0 = \Delta U = \Delta U_{body} + \Delta U_{water}$$

or
$$[mc_v(T_2 - T_1)]_{body} + [mc_v(T_2 - T_1)]_{water} = 0$$

Substituting $(68 \text{ kg})(3.6 \text{ kJ/kg·°C})(T_f - 39)°C + (1 \text{ kg})(4.18 \text{ kJ/kg·°C})(T_f - 3)°C = 0$

It gives $T_f = 38.4°C$

Then $\Delta T = 39 - 38.4 = \mathbf{0.6°C}$

Therefore, the average body temperature of this person should drop about half a degree celsius.

4-128 A 0.2-L glass of water at 20°C is to be cooled with ice to 5°C. The amount of ice or cold water that needs to be added to the water is to be determined.

Assumptions **1** Thermal properties of the ice and water are constant. **2** Heat transfer to the glass is negligible. **3** There is no stirring by hand or a mechanical device (it will add energy).

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-3). The specific heat of ice at about 0°C is $c = 2.11$ kJ/kg·°C (Table A-3). The melting temperature and the heat of fusion of ice at 1 atm are 0°C and 333.7 kJ/kg,.

Analysis (*a*) 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

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

$$0 = \Delta U$$

$$0 = \Delta U_{ice} + \Delta U_{water}$$
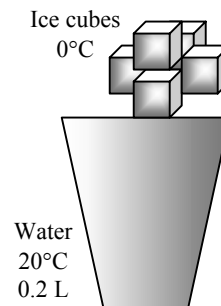
$$[mc(0°\text{C} - T_1)_{solid} + mh_{if} + mc(T_2 - 0°\text{C})_{liquid}]_{ice} + [mc(T_2 - T_1)]_{water} = 0$$

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

$$m[0 + 333.7\,\text{kJ/kg} + (4.18\,\text{kJ/kg·°C})(5\text{-}0)°\text{C}] + (0.2\,\text{kg})(4.18\,\text{kJ/kg·°C})(5\text{-}20)°\text{C} = 0$$

$$m = 0.0364\,\text{kg} = \mathbf{36.4\,g}$$

(*b*) When $T_{1,\,ice} = \text{-}8°\text{C}$ instead of 0°C, substituting gives

$$m[(2.11\,\text{kJ/kg·°C})[0\text{-}(\text{-}8)]°\text{C} + 333.7\,\text{kJ/kg} + (4.18\,\text{kJ/kg·°C})(5\text{-}0)°\text{C}]$$

$$+ (0.2\,\text{kg})(4.18\,\text{kJ/kg·°C})(5\text{-}20)°\text{C} = 0$$

$$m = 0.0347\,\text{kg} = \mathbf{34.7\,g}$$

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

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

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

Substituting,

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

It gives

$$m = 0.6\,\text{kg} = \mathbf{600\,g}$$

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. Also, the temperature of ice does not seem to make a significant difference.

4-129 EES Problem 4-128 is reconsidered. The effect of the initial temperature of the ice on the final mass of ice required as the ice temperature varies from -20°C to 0°C is to be investigated. The mass of ice is to be plotted against the initial temperature of ice.

Analysis The problem is solved using EES, and the solution is given below.

"Knowns"
rho_water = 1"[kg/L]"
V = 0.2 "[L]"
T_1_ice = 0"[C]"
T_1 = 20"[C]"
T_2 = 5"[C]"
C_ice = 2.11 "[kJ/kg-C]"
C_water = 4.18 "[kJ/kg-C]"
h_if = 333.7 "[kJ/kg]"
T_1_ColdWater = 0"[C]"

"The mass of the water is:"
m_water = rho_water*V "[kg]"

"The system is the water plus the ice. Assume a short time period and neglect
any heat and mass transfer. The energy balance becomes:"
E_in - E_out = DELTAE_sys "[kJ]"
E_in = 0 "[kJ]"
E_out = 0"[kJ]"
DELTAE_sys = DELTAU_water+DELTAU_ice"[kJ]"
DELTAU_water = m_water*C_water*(T_2 - T_1)"[kJ]"
DELTAU_ice = DELTAU_solid_ice+DELTAU_melted_ice"[kJ]"
DELTAU_solid_ice =m_ice*C_ice*(0-T_1_ice) + m_ice*h_if"[kJ]"
DELTAU_melted_ice=m_ice*C_water*(T_2 - 0)"[kJ]"
m_ice_grams=m_ice*convert(kg,g)"[g]"

"Cooling with Cold Water:"
DELTAE_sys = DELTAU_water+DELTAU_ColdWater"[kJ]"
DELTAU_water = m_water*C_water*(T_2_ColdWater - T_1)"[kJ]"
DELTAU_ColdWater = m_ColdWater*C_water*(T_2_ColdWater - T_1_ColdWater)"[kJ]"
m_ColdWater_grams=m_ColdWater*convert(kg,g)"[g]"

$m_{ice,grams}$ [g]	$T_{1,ice}$ [C]
31.6	-20
32.47	-15
33.38	-10
34.34	-5
35.36	0
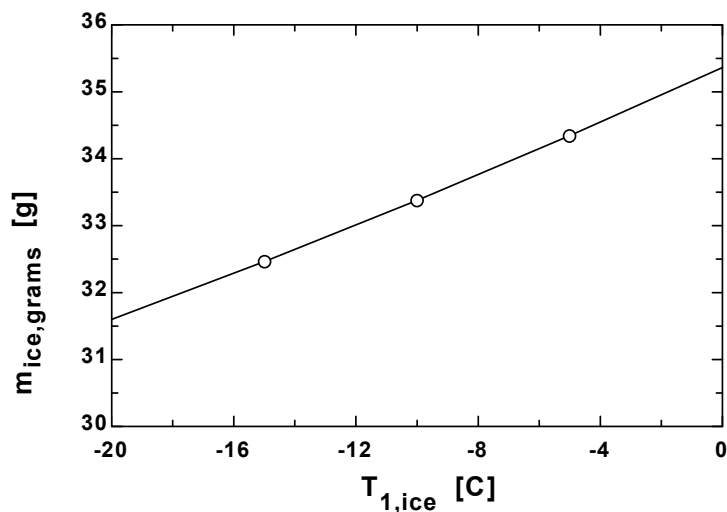
4-130 A 1- ton (1000 kg) of water is to be cooled in a tank by pouring ice into it. The final equilibrium temperature in the tank is to be determined.

Assumptions **1** Thermal properties of the ice and water are constant. **2** Heat transfer to the water tank is negligible. **3** There is no stirring by hand or a mechanical device (it will add energy).

Properties The specific heat of water at room temperature is $c = 4.18$ kJ/kg·°C, and the specific heat of ice at about 0°C is $c = 2.11$ kJ/kg·°C (Table A-3). The melting temperature and the heat of fusion of ice at 1 atm are 0°C and 333.7 kJ/kg.

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

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

$$0 = \Delta U$$

$$0 = \Delta U_{ice} + \Delta U_{water}$$
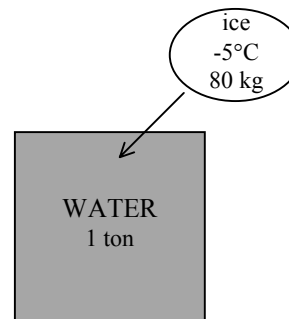
$$[mc(0°C - T_1)_{solid} + mh_{if} + mc(T_2 - 0°C)_{liquid}]_{ice} + [mc(T_2 - T_1)]_{water} = 0$$

Substituting,

$$(80 \text{ kg})\{(2.11 \text{ kJ/kg·°C})[0 - (-5)]°C + 333.7 \text{ kJ/kg} + (4.18 \text{ kJ/kg·°C})(T_2 - 0)°C\}$$

$$+(1000 \text{ kg})(4.18 \text{ kJ/kg·°C})(T_2 - 20)°C = 0$$

It gives $T_2 = \textbf{12.4°C}$

which is the final equilibrium temperature in the tank.

4-131 An insulated cylinder initially contains a saturated liquid-vapor mixture of water at a specified temperature. The entire vapor in the cylinder is to be condensed isothermally by adding ice inside the cylinder. The amount of ice that needs to be added is to be determined.

Assumptions **1** Thermal properties of the ice are constant. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** There is no stirring by hand or a mechanical device (it will add energy).

Properties The specific heat of ice at about 0°C is $c = 2.11$ kJ/kg·°C (Table A-3). The melting temperature and the heat of fusion of ice at 1 atm are given to be 0°C and 333.7 kJ/kg.

Analysis We take the contents of the cylinder (ice and saturated water) as our system, which is a closed system. Noting that the temperature and thus the pressure remains constant during this phase change process and thus $W_b + \Delta U = \Delta H$, the energy balance for this system can be written as

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

$$W_{b,in} = \Delta U \ \rightarrow \ \Delta H = 0$$

$$\Delta H_{ice} + \Delta H_{water} = 0$$

$$[mc(0°C - T_1)_{solid} + mh_{if} + mc(T_2 - 0°C)_{liquid}]_{ice} + [m(h_2 - h_1)]_{water} = 0$$

The properties of water at 120°C are (Table A-4)

$$\nu_f = 0.001060, \quad \nu_g = 0.89133 \text{ m}^3/\text{kg}$$
$$h_f = 503.81, \quad h_{fg} = 2202.1 \text{ kJ.kg}$$

Then,

$$\nu_1 = \nu_f + x_1\nu_{fg} = 0.001060 + 0.2 \times (0.89133 - 0.001060) = 0.17911 \text{ m}^3/\text{kg}$$

$$h_1 = h_f + x_1 h_{fg} = 503.81 + 0.2 \times 2202.1 = 944.24 \text{ kJ/kg}$$

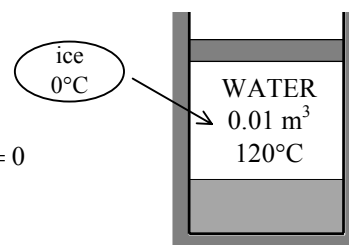$$h_2 = h_{f@120°C} = 503.81 \text{ kJ/kg}$$

$$m_{steam} = \frac{\nu_1}{\nu_1} = \frac{0.01 \text{ m}^3}{0.17911 \text{ m}^3/\text{kg}} = 0.05583 \text{ kg}$$

Noting that $T_{1, ice} = 0°C$ and $T_2 = 120°C$ and substituting gives

$$m[0 + 333.7 \text{ kJ/kg} + (4.18 \text{ kJ/kg·°C})(120\text{-}0)°C] + (0.05583 \text{ kg})(503.81 - 944.24) \text{ kJ/kg} = 0$$

$$m = 0.0294 \text{ kg} = \textbf{29.4 g ice}$$

4-132 The cylinder of a steam engine initially contains saturated vapor of water at 100 kPa. The cylinder is cooled by pouring cold water outside of it, and some of the steam inside condenses. If the piston is stuck at its initial position, the friction force acting on the piston and the amount of heat transfer are to be determined.

Assumptions The device is air-tight so that no air leaks into the cylinder as the pressure drops.

Analysis We take the contents of the cylinder (the saturated liquid-vapor mixture) as the system, which is a closed system. Noting that the volume remains constant during this phase change process, the energy balance for this system can be expressed as

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

$$-Q_{out} = \Delta U = m(u_2 - u_1)$$

The saturation properties of water at 100 kPa and at 30°C are (Tables A-4 and A-5)

$$P_1 = 100 \text{ kPa} \quad \longrightarrow \quad v_f = 0.001043 \text{ m}^3\text{/kg}, \; v_g = 1.6941 \text{ m}^3\text{/kg}$$
$$u_f = 417.40 \text{ kJ/kg}, \quad u_g = 2505.6 \text{ kJ/kg}$$

$$T_2 = 30°\text{C} \quad \longrightarrow \quad v_f = 0.001004 \text{ m}^3\text{/kg}, \; v_g = 32.879 \text{ m}^3\text{/kg}$$
$$u_f = 125.73 \text{ kJ/kg}, \quad u_{fg} = 2290.2 \text{ kJ/kg}$$
$$P_{sat} = 4.2469 \text{ kPa}$$

Then,

Cold water
Steam
0.05 m³
100 kPa

$$P_2 = P_{sat@30°C} = 4.2469 \text{ kPa}$$

$$v_1 = v_{g@100 \text{ kPa}} = 1.6941 \text{ m}^3\text{/kg}$$

$$u_1 = u_{g@100 \text{ kPa}} = 2505.6 \text{ kJ/kg}$$

and

$$m = \frac{V_1}{v_1} = \frac{0.05 \text{ m}^3}{1.6941 \text{ m}^3\text{/kg}} = 0.02951 \text{ kg}$$

$$v_2 = v_1 \longrightarrow x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{1.6941 - 0.001}{32.879 - 0.001} = 0.05150$$

$$u_2 = u_f + x_2 u_{fg} = 125.73 + 0.05150 \times 2290.2 = 243.67 \text{ kJ/kg}$$

The friction force that develops at the piston-cylinder interface balances the force acting on the piston, and is equal to

$$F = A(P_1 - P_2) = (0.1 \text{ m}^2)(100 - 4.2469)\text{kPa}\left(\frac{1000 \text{ N/m}^2}{1 \text{ kPa}}\right) = \mathbf{9575 \; N}$$

The heat transfer is determined from the energy balance to be

$$Q_{out} = m(u_1 - u_2)$$
$$= (0.02951 \text{ kg})(2505.6 - 243.67)\text{kJ/kg}$$
$$= \mathbf{66.8 \; kJ}$$
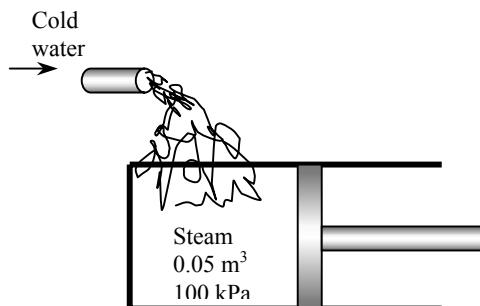
4-133 Water is boiled at sea level (1 atm pressure) in a coffee maker, and half of the water evaporates in 25 min. The power rating of the electric heating element and the time it takes to heat the cold water to the boiling temperature are to be determined.

Assumptions **1** The electric power consumption by the heater is constant. **2** Heat losses from the coffee maker are negligible.

Properties The enthalpy of vaporization of water at the saturation temperature of 100°C is h_{fg} = 2256.4 kJ/kg (Table A-4). At an average temperature of (100+18)/2 = 59°C, the specific heat of water is c = 4.18 kJ/kg.°C, and the density is about 1 kg/L (Table A-3).

Analysis The density of water at room temperature is very nearly 1 kg/L, and thus the mass of 1 L water at 18°C is nearly 1 kg. Noting that the enthalpy of vaporization represents the amount of energy needed to vaporize a liquid at a specified temperature, the amount of electrical energy needed to vaporize 0.5 kg of water in 25 min is
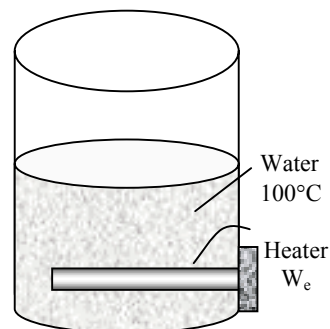
$$W_e = \dot{W}_e \Delta t = mh_{fg} \;\rightarrow\; \dot{W}_e = \frac{mh_{fg}}{\Delta t} = \frac{(0.5\,\text{kg})(2256.4\,\text{kJ/kg})}{(25 \times 60\,\text{s})} = \textbf{0.752 kW}$$

Therefore, the electric heater consumes (and transfers to water) 0.752 kW of electric power.

Noting that the specific heat of water at the average temperature of (18+100)/2 = 59°C is c = 4.18 kJ/kg·°C, the time it takes for the entire water to be heated from 18°C to 100°C is determined to be

$$W_e = \dot{W}_e \Delta t = mc\Delta T \;\rightarrow\; \Delta t = \frac{mc\Delta T}{\dot{W}_e} = \frac{(1\,\text{kg})(4.18\,\text{kJ/kg}\cdot\text{°C})(100-18)\text{°C}}{0.752\,\text{kJ/s}} = 456\,\text{s} = \textbf{7.60 min}$$

Discussion We can also solve this problem using v_f data (instead of density), and h_f data instead of specific heat. At 100°C, we have v_f = 0.001043 m³/kg and h_f = 419.17 kJ/kg. At 18°C, we have h_f = 75.54 kJ/kg (Table A-4). The two results will be practically the same.

4-134 Two rigid tanks that contain water at different states are connected by a valve. The valve is opened and the two tanks come to the same state at the temperature of the surroundings. The final pressure and the amount of heat transfer are to be determined.

Assumptions **1** The tanks are stationary and thus the kinetic and potential energy changes are zero. **2** The tank is insulated and thus heat transfer is negligible. **3** There are no work interactions.

Analysis We take the entire contents of the tank as the system. This is a closed system since no mass enters or leaves. Noting that the volume of the system is constant and thus there is no boundary work, the energy balance for this stationary closed system can be expressed as
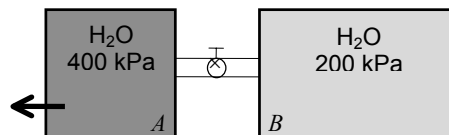
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$-Q_{\text{out}} = \Delta U = (\Delta U)_A + (\Delta U)_B \quad (\text{since } W = \text{KE} = \text{PE} = 0)$$

$$Q_{\text{out}} = -[U_{2,A+B} - U_{1,A} - U_{1,B}]$$

$$= -[m_{2,\text{total}} u_2 - (m_1 u_1)_A - (m_1 u_1)_B]$$

The properties of water in each tank are (Tables A-4 through A-6)

Tank A:

$$P_1 = 400 \text{ kPa} \left.\begin{array}{l} \end{array}\right\} \quad v_f = 0.001084, \quad v_g = 0.46242 \text{ m}^3/\text{kg}$$
$$x_1 = 0.80 \qquad u_f = 604.22, \qquad u_{fg} = 1948.9 \text{ kJ/kg}$$

$$v_{1,A} = v_f + x_1 v_{fg} = 0.001084 + [0.8 \times (0.46242 - 0.001084)] = 0.37015 \text{ m}^3/\text{kg}$$

$$u_{1,A} = u_f + x_1 u_{fg} = 604.22 + (0.8 \times 1948.9) = 2163.3 \text{ kJ/kg}$$

Tank B:

$$P_1 = 200 \text{ kPa} \left.\begin{array}{l} \end{array}\right\} \quad v_{1,B} = 1.1989 \text{ m}^3/\text{kg}$$
$$T_1 = 250°\text{C} \qquad u_{1,B} = 2731.4 \text{ kJ/kg}$$

$$m_{1,A} = \frac{V_A}{v_{1,A}} = \frac{0.2 \text{ m}^3}{0.37015 \text{ m}^3/\text{kg}} = 0.5403 \text{ kg}$$

$$m_{1,B} = \frac{V_B}{v_{1,B}} = \frac{0.5 \text{ m}^3}{1.1989 \text{ m}^3/\text{kg}} = 0.4170 \text{ kg}$$

$$m_t = m_{1,A} + m_{1,B} = 0.5403 + 0.4170 = 0.9573 \text{ kg}$$

$$v_2 = \frac{V_t}{m_t} = \frac{0.7 \text{ m}^3}{0.9573 \text{ kg}} = 0.73117 \text{ m}^3/\text{kg}$$

$$T_2 = 25°\text{C} \qquad\qquad\quad \left.\begin{array}{l} \end{array}\right\} \quad v_f = 0.001003, \quad v_g = 43.340 \text{ m}^3/\text{kg}$$
$$v_2 = 0.73117 \text{ m}^3/\text{kg} \qquad u_f = 104.83, \qquad u_{fg} = 2304.3 \text{ kJ/kg}$$

Thus at the final state the system will be a saturated liquid-vapor mixture since $v_f < v_2 < v_g$. Then the final pressure must be

$$P_2 = P_{\text{sat @ 25 °C}} = \textbf{3.17 kPa}$$

Also,

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.73117 - 0.001}{43.340 - 0.001} = 0.01685$$

$$u_2 = u_f + x_2 u_{fg} = 104.83 + (0.01685 \times 2304.3) = 143.65 \text{ kJ/kg}$$

Substituting, $\quad Q_{\text{out}} = -[(0.9573)(143.65) - (0.5403)(2163.3) - (0.4170)(2731.4)] = \textbf{2170 kJ}$

4-135 EES Problem 4-134 is reconsidered. The effect of the environment temperature on the final pressure and the heat transfer as the environment temperature varies from 0°C to 50°C is to be investigated. The final results are to be plotted against the environment temperature.

Analysis The problem is solved using EES, and the solution is given below.

"Knowns"
Vol_A=0.2 [m^3]
P_A[1]=400 [kPa]
x_A[1]=0.8
T_B[1]=250 [C]
P_B[1]=200 [kPa]
Vol_B=0.5 [m^3]
T_final=25 [C] "T_final = T_surroundings. To do the parametric study
or to solve the problem when Q_out = 0, place this statement in {}."
{Q_out=0 [kJ]} "To determine the surroundings temperature that
makes Q_out = 0, remove the {} and resolve the problem."

"Solution"
"Conservation of Energy for the combined tanks:"
E_in-E_out=DELTAE
E_in=0
E_out=Q_out
DELTAE=m_A*(u_A[2]-u_A[1])+m_B*(u_B[2]-u_B[1])
m_A=Vol_A/v_A[1]
m_B=Vol_B/v_B[1]
Fluid$='Steam_IAPWS'
u_A[1]=INTENERGY(Fluid$,P=P_A[1], x=x_A[1])
v_A[1]=volume(Fluid$,P=P_A[1], x=x_A[1])
T_A[1]=temperature(Fluid$,P=P_A[1], x=x_A[1])
u_B[1]=INTENERGY(Fluid$,P=P_B[1],T=T_B[1])
v_B[1]=volume(Fluid$,P=P_B[1],T=T_B[1])
"At the final state the steam has uniform properties through out the entire system."
u_B[2]=u_final
u_A[2]=u_final
m_final=m_A+m_B
Vol_final=Vol_A+Vol_B
v_final=Vol_final/m_final
u_final=INTENERGY(Fluid$,T=T_final, v=v_final)
P_final=pressure(Fluid$,T=T_final, v=v_final)

P_{final} [kPa]	Q_{out} [kJ]	T_{final} [C]
0.6112	2300	0
0.9069	2274	5.556
1.323	2247	11.11
1.898	2218	16.67
2.681	2187	22.22
3.734	2153	27.78
5.13	2116	33.33
6.959	2075	38.89
9.325	2030	44.44
12.35	1978	50
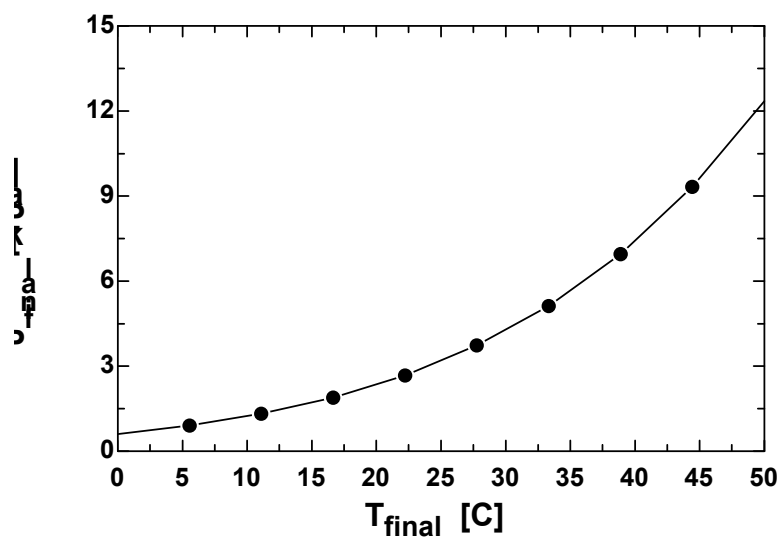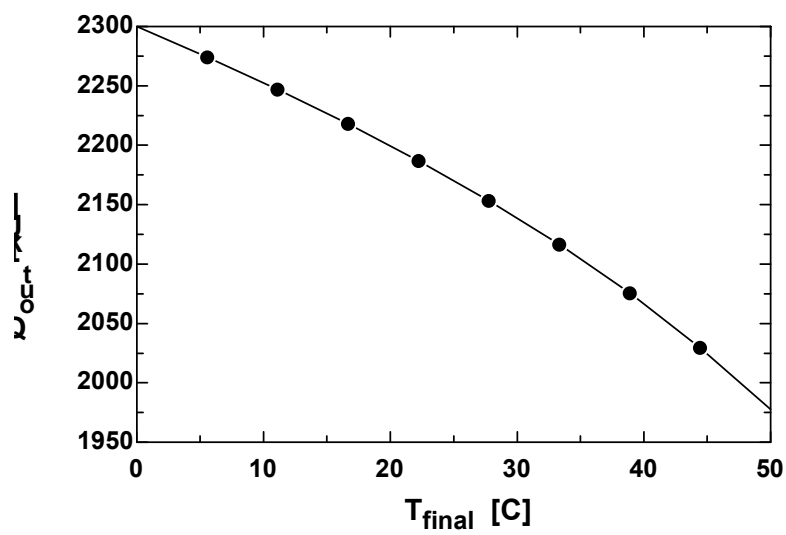
4-136 A rigid tank filled with air is connected to a cylinder with zero clearance. The valve is opened, and air is allowed to flow into the cylinder. The temperature is maintained at 30°C at all times. The amount of heat transfer with the surroundings is to be determined.

Assumptions **1** Air is an ideal gas. **2** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **3** There are no work interactions involved other than the boundary work.

Properties The gas constant of air is $R = 0.287$ kPa.m^3/kg.K (Table A-1).

Analysis We take the entire air in the tank and the cylinder to be the system. This is a closed system since no mass crosses the boundary of the system. The energy balance for this closed system can be expressed as

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

$$Q_{in} - W_{b,out} = \Delta U = m(u_2 - u_1) = 0$$

$$Q_{in} = W_{b,out}$$
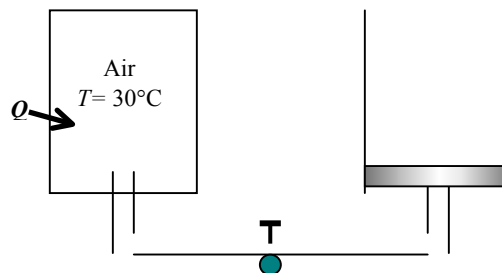
since $u = u(T)$ for ideal gases, and thus $u_2 = u_1$ when $T_1 = T_2$. The initial volume of air is

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \longrightarrow V_2 = \frac{P_1}{P_2}\frac{T_2}{T_1}V_1 = \frac{400 \text{ kPa}}{200 \text{ kPa}} \times 1 \times (0.4 \text{ m}^3) = 0.80 \text{ m}^3$$

The pressure at the piston face always remains constant at 200 kPa. Thus the boundary work done during this process is

$$W_{b,out} = \int_1^2 Pd V = P_2(V_2 - V_1) = (200 \text{ kPa})(0.8 - 0.4)\text{m}^3 \left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right) = 80 \text{ kJ}$$

Therefore, the heat transfer is determined from the energy balance to be

$$W_{b,out} = Q_{in} = \mathbf{80 \text{ kJ}}$$

4-137 A well-insulated room is heated by a steam radiator, and the warm air is distributed by a fan. The average temperature in the room after 30 min is to be determined.

Assumptions **1** Air is an ideal gas with constant specific heats at room temperature. **2** The kinetic and potential energy changes are negligible. **3** The air pressure in the room remains constant and thus the air expands as it is heated, and some warm air escapes.

Properties The gas constant of air is $R = 0.287$ kPa.m³/kg.K (Table A-1). Also, $c_p = 1.005$ kJ/kg.K for air at room temperature (Table A-2).

Analysis We first take the radiator as the system. This is a closed system since no mass enters or leaves. The energy balance for this closed system can be expressed as

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

$$-Q_{out} = \Delta U = m(u_2 - u_1) \quad (\text{since } W = KE = PE = 0)$$

$$Q_{out} = m(u_1 - u_2)$$

Using data from the steam tables (Tables A-4 through A-6), some properties are determined to be

$$\left. \begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 200°C \end{array} \right\} \begin{array}{l} \nu_1 = 1.08049 \text{ m}^3\text{/kg} \\ u_1 = 2654.6 \text{ kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_2 = 100 \text{ kPa} \\ (\nu_2 = \nu_1) \end{array} \right\} \begin{array}{l} \nu_f = 0.001043, \quad \nu_g = 1.6941 \text{ m}^3\text{/kg} \\ u_f = 417.40, \quad u_{fg} = 2088.2 \text{ kJ/kg} \end{array}$$

$$x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{1.08049 - 0.001043}{1.6941 - 0.001043} = 0.6376$$

$$u_2 = u_f + x_2 u_{fg} = 417.40 + 0.6376 \times 2088.2 = 1748.7 \text{ kJ/kg}$$

$$m = \frac{V_1}{\nu_1} = \frac{0.015 \text{ m}^3}{1.08049 \text{ m}^3\text{/kg}} = 0.0139 \text{ kg}$$

Substituting, $\quad Q_{out} = (0.0139 \text{ kg})(2654.6 - 1748.7)\text{kJ/kg} = 12.58 \text{ kJ}$

The volume and the mass of the air in the room are $V = 4 \times 4 \times 5 = 80$ m³ and

$$m_{air} = \frac{P_1 V_1}{RT_1} = \frac{(100 \text{ kPa})(80 \text{ m}^3)}{(0.2870 \text{ kPa} \cdot \text{m}^3\text{/kg} \cdot \text{K})(283 \text{ K})} = 98.5 \text{ kg}$$

The amount of fan work done in 30 min is

$$W_{fan,in} = \dot{W}_{fan,in} \Delta t = (0.120 \text{ kJ/s})(30 \times 60 \text{ s}) = 216\text{kJ}$$

We now take the air in the room as the system. The energy balance for this closed system is expressed as

$$E_{in} - E_{out} = \Delta E_{system}$$

$$Q_{in} + W_{fan,in} - W_{b,out} = \Delta U$$

$$Q_{in} + W_{fan,in} = \Delta H \cong mc_p(T_2 - T_1)$$

since the boundary work and ΔU combine into ΔH for a constant pressure expansion or compression process. It can also be expressed as

$$(\dot{Q}_{in} + \dot{W}_{fan,in})\Delta t = mc_{p,avg}(T_2 - T_1)$$

Substituting, $\quad (12.58 \text{ kJ}) + (216 \text{ kJ}) = (98.5 \text{ kg})(1.005 \text{ kJ/kg°C})(T_2 - 10)°C$

which yields $\quad T_2 = \mathbf{12.3°C}$

Therefore, the air temperature in the room rises from 10°C to 12.3°C in 30 min.

10°C
4 m × 4 m × 5 m

Steam
radiator
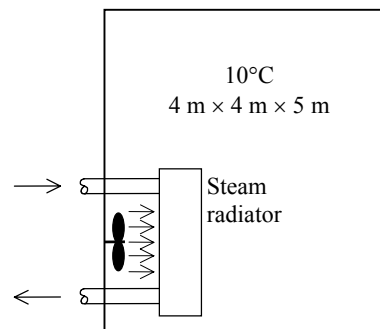
4-138 An insulated cylinder is divided into two parts. One side of the cylinder contains N_2 gas and the other side contains He gas at different states. The final equilibrium temperature in the cylinder when thermal equilibrium is established is to be determined for the cases of the piston being fixed and moving freely.

Assumptions **1** Both N_2 and He are ideal gases with constant specific heats. **2** The energy stored in the container itself is negligible. **3** The cylinder is well-insulated and thus heat transfer is negligible.

Properties The gas constants and the constant volume specific heats are $R = 0.2968$ kPa.m^3/kg.K is $c_v = 0.743$ kJ/kg·°C for N_2, and $R = 2.0769$ kPa.m^3/kg.K is $c_v = 3.1156$ kJ/kg·°C for He (Tables A-1 and A-2)

Analysis The mass of each gas in the cylinder is

$$m_{N_2} = \left(\frac{P_1 V_1}{RT_1}\right)_{N_2} = \frac{(500 \text{ kPa})(1 \text{ m}^3)}{(0.2968 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(353 \text{ K})} = 4.77 \text{ kg}$$

$$m_{He} = \left(\frac{P_1 V_1}{RT_1}\right)_{He} = \frac{(500 \text{ kPa})(1 \text{ m}^3)}{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(298 \text{ K})} = 0.808 \text{ kg}$$

N_2	He
1 m^3	1 m^3
500 kPa	500 kPa
80°C	25°C

Taking the entire contents of the cylinder as our system, the 1st law relation can be written as

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

$$0 = \Delta U = (\Delta U)_{N_2} + (\Delta U)_{He}$$

$$0 = [mc_v (T_2 - T_1)]_{N_2} + [mc_v (T_2 - T_1)]_{He}$$

Substituting,

$$(4.77 \text{ kg})(0.743 \text{ kJ/kg·°C})(T_f - 80)°C + (0.808 \text{ kg})(3.1156 \text{ kJ/kg·°C})(T_f - 25)°C = 0$$

It gives $\qquad T_f = \textbf{57.2°C}$

where T_f is the final equilibrium temperature in the cylinder.

The answer would be the **same** if the piston were not free to move since it would effect only pressure, and not the specific heats.

Discussion Using the relation $PV = NR_u T$, it can be shown that the total number of moles in the cylinder is $0.170 + 0.202 = 0.372$ kmol, and the final pressure is 510.6 kPa.

4-139 An insulated cylinder is divided into two parts. One side of the cylinder contains N_2 gas and the other side contains He gas at different states. The final equilibrium temperature in the cylinder when thermal equilibrium is established is to be determined for the cases of the piston being fixed and moving freely.

Assumptions 1 Both N_2 and He are ideal gases with constant specific heats. **2** The energy stored in the container itself, except the piston, is negligible. **3** The cylinder is well-insulated and thus heat transfer is negligible. **4** Initially, the piston is at the average temperature of the two gases.

Properties The gas constants and the constant volume specific heats are $R = 0.2968$ kPa.m³/kg.K is $c_v = 0.743$ kJ/kg·°C for N_2, and $R = 2.0769$ kPa.m³/kg.K is $c_v = 3.1156$ kJ/kg·°C for He (Tables A-1 and A-2). The specific heat of copper piston is $c = 0.386$ kJ/kg·°C (Table A-3).

Analysis The mass of each gas in the cylinder is

$$m_{N_2} = \left(\frac{P_1 V_1}{RT_1}\right)_{N_2} = \frac{(500 \text{ kPa})(1 \text{ m}^3)}{(0.2968 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(353 \text{ K})} = 4.77 \text{ kg}$$

$$m_{He} = \left(\frac{P_1 V_1}{RT_1}\right)_{He} = \frac{(500 \text{ kPa})(1 \text{ m}^3)}{(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(353 \text{ K})} = 0.808 \text{ kg}$$
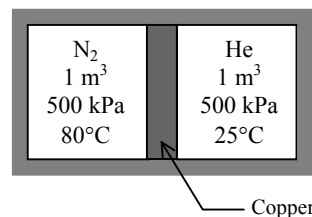
N_2	He
1 m³	1 m³
500 kPa	500 kPa
80°C	25°C

— Copper

Taking the entire contents of the cylinder as our system, the 1st law relation can be written as

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

$$0 = \Delta U = (\Delta U)_{N_2} + (\Delta U)_{He} + (\Delta U)_{Cu}$$

$$0 = [mc_v(T_2 - T_1)]_{N_2} + [mc_v(T_2 - T_1)]_{He} + [mc(T_2 - T_1)]_{Cu}$$

where

$$T_{1,\,Cu} = (80 + 25)\,/\,2 \; = \; 52.5°C$$

Substituting,

$$(4.77 \text{ kg})(0.743 \text{ kJ/kg·°C})(T_f - 80)°C + (0.808 \text{ kg})(3.1156 \text{ kJ/kg·°C})(T_f - 25)°C$$
$$+ (5.0 \text{ kg})(0.386 \text{ kJ/kg·°C})(T_f - 52.5)°C = 0$$

It gives

$$T_f = \textbf{56.0°C}$$

where T_f is the final equilibrium temperature in the cylinder.

The answer would be the **same** if the piston were not free to move since it would effect only pressure, and not the specific heats.

4-140 EES Problem 4-139 is reconsidered. The effect of the mass of the copper piston on the final equilibrium temperature as the mass of piston varies from 1 kg to 10 kg is to be investigated. The final temperature is to be plotted against the mass of piston.

Analysis The problem is solved using EES, and the solution is given below.

"Knowns:"
R_u=8.314 [kJ/kmol-K]
V_N2[1]=1 [m^3]
Cv_N2=0.743 [kJ/kg-K] "From Table A-2(a) at 27C"
R_N2=0.2968 [kJ/kg-K] "From Table A-2(a)"
T_N2[1]=80 [C]
P_N2[1]=500 [kPa]
V_He[1]=1 [m^3]
Cv_He=3.1156 [kJ/kg-K] "From Table A-2(a) at 27C"
T_He[1]=25 [C]
P_He[1]=500 [kPa]
R_He=2.0769 [kJ/kg-K] "From Table A-2(a)"
m_Pist=5 [kg]
Cv_Pist=0.386 [kJ/kg-K] "Use Cp for Copper from Table A-3(b) at 27C"

"Solution:"

"mass calculations:"
P_N2[1]*V_N2[1]=m_N2*R_N2*(T_N2[1]+273)
P_He[1]*V_He[1]=m_He*R_He*(T_He[1]+273)

"The entire cylinder is considered to be a closed system, neglecting the piston."
"Conservation of Energy for the closed system:"
"E_in - E_out = DELTAE_negPist, we neglect DELTA KE and DELTA PE for the cylinder."
E_in - E_out = DELTAE_neglPist
E_in =0 [kJ]
E_out = 0 [kJ]

"At the final equilibrium state, N2 and He will have a common temperature."
DELTAE_neglPist= m_N2*Cv_N2*(T_2_neglPist-T_N2[1])+m_He*Cv_He*(T_2_neglPist-T_He[1])
"The entire cylinder is considered to be a closed system, including the piston."
"Conservation of Energy for the closed system:"
"E_in - E_out = DELTAE_withPist, we neglect DELTA KE and DELTA PE for the cylinder."
E_in - E_out = DELTAE_withPist

"At the final equilibrium state, N2 and He will have a common temperature."
DELTAE_withPist= m_N2*Cv_N2*(T_2_withPist-T_N2[1])+m_He*Cv_He*(T_2_withPist-T_He[1])+m_Pist*Cv_Pist*(T_2_withPist-T_Pist[1])
T_Pist[1]=(T_N2[1]+T_He[1])/2
"Total volume of gases:"
V_total=V_N2[1]+V_He[1]
"Final pressure at equilibrium:"
"Neglecting effect of piston, P_2 is:"
P_2_neglPist*V_total=N_total*R_u*(T_2_neglPist+273)

"Including effect of piston, P_2 is:"
N_total=m_N2/molarmass(nitrogen)+m_He/molarmass(Helium)
P_2_withPist*V_total=N_total*R_u*(T_2_withPist+273)

m_{Pist} [kg]	$T_{2,neglPist}$ [C]	$T_{2,withPist}$ [C]
1	57.17	56.89
2	57.17	56.64
3	57.17	56.42
4	57.17	56.22
5	57.17	56.04
6	57.17	55.88
7	57.17	55.73
8	57.17	55.59
9	57.17	55.47
10	57.17	55.35
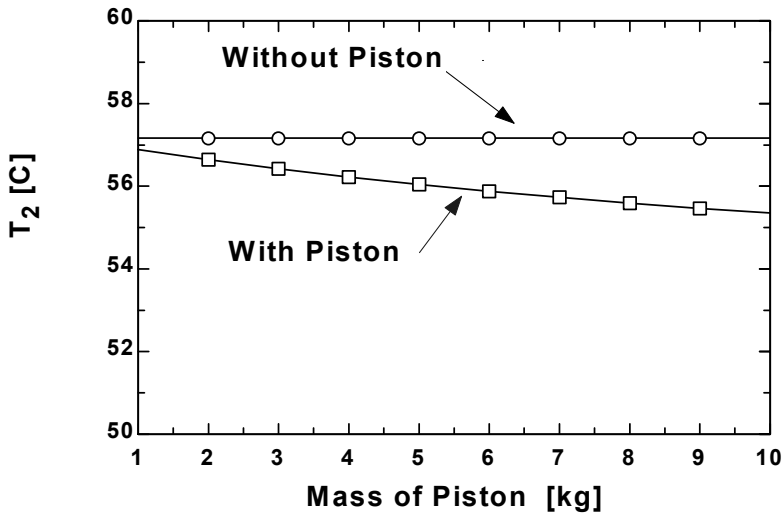
4-141 An insulated rigid tank initially contains saturated liquid water and air. An electric resistor placed in the tank is turned on until the tank contains saturated water vapor. The volume of the tank, the final temperature, and the power rating of the resistor are to be determined.

***Assumptions* 1** The tank is stationary and thus the kinetic and potential energy changes are zero. **2** There are no work interactions.

Properties The initial properties of steam are (Table A-4)

$$T_1 = 200°C \left|\begin{array}{l} v_1 = 0.001157 \text{ m}^3/\text{kg} \\ x_1 = 0 \end{array}\right. u_1 = 850.46 \text{ kJ/kg}$$

Analysis (*a*) We take the contents of the tank as the system. This is a closed system since no mass enters or leaves. Noting that the volume of the system is constant and thus there is no boundary work, the energy balance for this stationary closed system can be expressed as

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

$$W_{e,in} = \Delta U = m(u_2 - u_1) \quad (\text{since } Q = KE = PE = 0)$$

The initial water volume and the tank volume are

$$V_1 = m v_1 = (1.4 \text{ kg})(0.001157 \text{ m}^3/\text{kg}) = 0.001619 \text{ m}^3$$

$$V_{tank} = \frac{0.001619 \text{ m}^3}{0.25} = \mathbf{0.006476 \text{ m}^3}$$

(*b*) Now, the final state can be fixed by calculating specific volume

$$v_2 = \frac{V_2}{m} = \frac{0.006476 \text{ m}^3}{1.4 \text{ kg}} = 0.004626 \text{ m}^3/\text{kg}$$

The final state properties are

$$v_2 = 0.004626 \text{ m}^3/\text{kg} \left|\begin{array}{l} T_2 = \mathbf{371.3°C} \\ x_2 = 1 \end{array}\right. u_2 = 2201.5 \text{ kJ/kg}$$

(*c*) Substituting,

$$W_{e,in} = (1.4 \text{ kg})(2201.5 - 850.46)\text{kJ/kg} = 1892 \text{ kJ}$$

Finally, the power rating of the resistor is

$$\dot{W}_{e,in} = \frac{W_{e,in}}{\Delta t} = \frac{1892 \text{ kJ}}{20 \times 60 \text{ s}} = \mathbf{1.576 \text{ kW}}$$
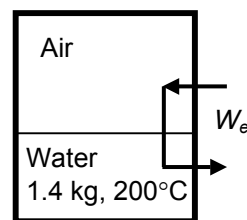
4-142 A piston-cylinder device contains an ideal gas. An external shaft connected to the piston exerts a force. For an isothermal process of the ideal gas, the amount of heat transfer, the final pressure, and the distance that the piston is displaced are to be determined.

Assumptions **1** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **2** The friction between the piston and the cylinder is negligible.

Analysis (*a*) We take the ideal gas in the cylinder to be the system. This is a closed system since no mass crosses the system boundary. The energy balance for this stationary closed system can be expressed as
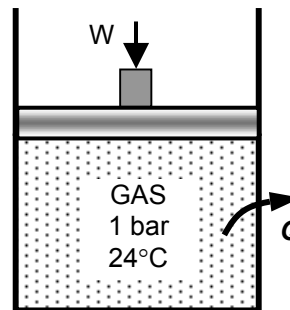
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$W_{\text{b,in}} - Q_{\text{out}} = \Delta U_{\text{ideal gas}} \cong mc_v (T_2 - T_1)_{\text{ideal gas}}) = 0 \quad (\text{since } T_2 = T_1 \text{ and } KE = PE = 0)$$

$$W_{\text{b,in}} = Q_{\text{out}}$$

Thus, the amount of heat transfer is equal to the boundary work input

$$Q_{\text{out}} = W_{\text{b,in}} = \mathbf{0.1\,kJ}$$

(*b*) The relation for the isothermal work of an ideal gas may be used to determine the final volume in the cylinder. But we first calculate initial volume

$$V_1 = \frac{\pi D^2}{4} L_1 = \frac{\pi (0.12\,\text{m})^2}{4} (0.2\,\text{m}) = 0.002262\,\text{m}^3$$

Then,

$$W_{\text{b,in}} = -P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$0.1\,\text{kJ} = -(100 \ \text{kPa})(0.002262 \ \text{m}^3)\ln\left(\frac{V_2}{0.002262 \ \text{m}^3}\right) \longrightarrow V_2 = 0.001454 \ \text{m}^3$$

The final pressure can be determined from ideal gas relation applied for an isothermal process

$$P_1 V_1 = P_2 V_2 \longrightarrow (100\,\text{kPa})(0.002262\,\text{m}^3) = P_2\,(0.001454\,\text{m}^3) \longrightarrow P_2 = \mathbf{155.6\,kPa}$$

(*c*) The final position of the piston and the distance that the piston is displaced are

$$V_2 = \frac{\pi D^2}{4} L_2 \longrightarrow 0.001454\,\text{m}^3 = \frac{\pi (0.12\,\text{m})^2}{4} L_2 \longrightarrow L_2 = 0.1285\,\text{m}$$

$$\Delta L = L_1 - L_2 = 0.20 - 0.1285 = 0.07146\,\text{m} = \mathbf{7.1\,cm}$$

4-143 A piston-cylinder device with a set of stops contains superheated steam. Heat is lost from the steam. The pressure and quality (if mixture), the boundary work, and the heat transfer until the piston first hits the stops and the total heat transfer are to be determined.

Assumptions **1** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **2** The friction between the piston and the cylinder is negligible.

Analysis (*a*) We take the steam in the cylinder to be the system. This is a closed system since no mass crosses the system boundary. The energy balance for this stationary closed system can be expressed as

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

$$W_{b,in} - Q_{out} = \Delta U \quad \text{(since } KE = PE = 0)$$

Denoting when piston first hits the stops as state (2) and the final state as (3), the energy balance relations may be written as

$$W_{b,in} - Q_{out,1-2} = m(u_2 - u_1)$$
$$W_{b,in} - Q_{out,1-3} = m(u_3 - u_1)$$

The properties of steam at various states are (Tables A-4 through A-6)

$$T_{sat@3.5\,MPa} = 242.56°C$$

$$T_1 = T_1 + \Delta T_{sat} = 242.56 + 5 = 247.56°C$$

$$\left. \begin{array}{l} P_1 = 3.5\,\text{MPa} \\ T_1 = 247.56°C \end{array} \right\} \begin{array}{l} v_1 = 0.05821\,\text{m}^3/\text{kg} \\ u_1 = 2617.3\,\text{kJ/kg} \end{array}$$

$$\left. \begin{array}{l} P_2 = P_1 = 3.5\,\text{MPa} \\ x_2 = 0 \end{array} \right\} \begin{array}{l} v_2 = 0.001235\,\text{m}^3/\text{kg} \\ u_2 = 1045.4\,\text{kJ/kg} \end{array}$$

$$\left. \begin{array}{l} v_3 = v_2 = 0.001235\,\text{m}^3/\text{kg} \\ T_3 = 200°C \end{array} \right\} \begin{array}{l} x_3 = \textbf{0.00062} \\ P_3 = \textbf{1555 kPa} \\ u_3 = 851.55\,\text{kJ/kg} \end{array}$$

(*b*) Noting that the pressure is constant until the piston hits the stops during which the boundary work is done, it can be determined from its definition as

$$W_{b,in} = mP_1(v_1 - v_2) = (0.15\,\text{kg})(3500\,\text{kPa})(0.05821 - 0.001235)\text{m}^3 = \textbf{29.91 kJ}$$

(*c*) Substituting into energy balance relations,

$$Q_{out,1-2} = 29.91\,\text{kJ} - (0.15\,\text{kg})(1045.4 - 2617.3)\text{kJ/kg} = \textbf{265.7 kJ}$$

(*d*) $\quad Q_{out,1-3} = 29.91\,\text{kJ} - (0.15\,\text{kg})(851.55 - 2617.3)\text{kJ/kg} = \textbf{294.8 kJ}$
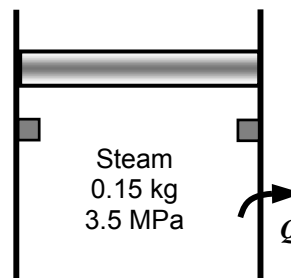
4-144 An insulated rigid tank is divided into two compartments, each compartment containing the same ideal gas at different states. The two gases are allowed to mix. The simplest expression for the mixture temperature in a specified format is to be obtained.

Analysis We take the both compartments together as the system. This is a closed system since no mass enters or leaves. The energy balance for this stationary closed system can be expressed as

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

$$0 = \Delta U \quad (\text{since } Q = W = KE = PE = 0)$$

$$0 = m_1 c_v (T_3 - T_1) + m_2 c_v (T_3 - T_2)$$

$$(m_1 + m_2)T_3 = m_1 T_1 + m_2 T_2$$
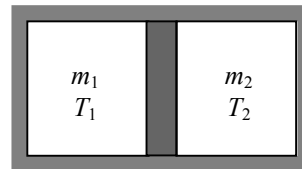
and, $\quad m_3 = m_1 + m_2$

Solving for final temperature, we find

$$T_3 = \frac{m_1}{m_3} T_1 + \frac{m_2}{m_3} T_2$$

4-145 A relation for the explosive energy of a fluid is given. A relation is to be obtained for the explosive energy of an ideal gas, and the value for air at a specified state is to be evaluated.

Properties The specific heat ratio for air at room temperature is $k = 1.4$.

Analysis The explosive energy per unit volume is given as

$$e_{explosion} = \frac{u_1 - u_2}{v_1}$$

For an ideal gas, $\quad u_1 - u_2 = c_v(T_1 - T_2)$

$$c_p - c_v = R$$

$$v_1 = \frac{RT_1}{P_1}$$

and thus

$$\frac{c_v}{R} = \frac{c_v}{c_p - c_v} = \frac{1}{c_p / c_v - 1} = \frac{1}{k-1}$$

Substituting,

$$e_{explosion} = \frac{c_v(T_1 - T_2)}{RT_1 / P_1} = \frac{P_1}{k-1}\left(1 - \frac{T_2}{T_1}\right)$$

which is the desired result.

Using the relation above, the total explosive energy of 20 m³ of air at 5 MPa and 100°C when the surroundings are at 20°C is determined to be

$$E_{explosion} = Ve_{explosion} = \frac{P_1 V_1}{k-1}\left(1 - \frac{T_2}{T_1}\right) = \frac{(5000 \text{ kPa})(20 \text{ m}^3)}{1.4 - 1}\left(1 - \frac{293 \text{ K}}{373 \text{ K}}\right)\left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right) = \textbf{53,619 kJ}$$

4-146 Using the relation for explosive energy given in the previous problem, the explosive energy of steam and its TNT equivalent at a specified state are to be determined.

Assumptions Steam condenses and becomes a liquid at room temperature after the explosion.

Properties The properties of steam at the initial and the final states are (Table A-4 through A-6)

$$\left.\begin{array}{l} P_1 = 10 \text{ MPa} \\ T_1 = 500°C \end{array}\right\} \begin{array}{l} v_1 = 0.032811 \text{ m}^3/\text{kg} \\ u_1 = 3047.0 \text{ kJ/kg} \end{array}$$

$$\left.\begin{array}{l} T_2 = 25°C \\ \text{Comp. liquid} \end{array}\right\} u_2 \cong u_{f@25°C} = 104.83 \text{ kJ/kg}$$
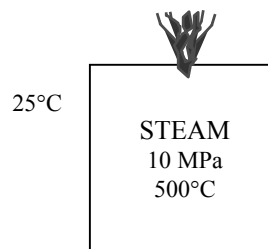
Analysis The mass of the steam is

$$m = \frac{V}{v_1} = \frac{20 \text{ m}^3}{0.032811 \text{ m}^3/\text{kg}} = 609.6 \text{ kg}$$

Then the total explosive energy of the steam is determined from

$$E_{explosive} = m(u_1 - u_2) = (609.6 \text{ kg})(3047.0 - 104.83)\text{kJ/kg} = \textbf{1,793,436 kJ}$$

which is equivalent to

$$\frac{1,793,436 \text{ kJ}}{3250 \text{ kJ/kg of TNT}} = \textbf{551.8 kg of TNT}$$

Fundamentals of Engineering (FE) Exam Problems

4-147 A room is filled with saturated steam at 100°C. Now a 5-kg bowling ball at 25°C is brought to the room. Heat is transferred to the ball from the steam, and the temperature of the ball rises to 100°C while some steam condenses on the ball as it loses heat (but it still remains at 100°C). The specific heat of the ball can be taken to be 1.8 kJ/kg.°C. The mass of steam that condensed during this process is
(a) 80 g (b) 128 g (c) 299 g (d) 351 g (e) 405 g

Answer (c) 299 g

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

m_ball=5 "kg"
T=100 "C"
T1=25 "C"
T2=100 "C"
Cp=1.8 "kJ/kg.C"
Q=m_ball*Cp*(T2-T1)
Q=m_steam*h_fg "kJ"
h_f=ENTHALPY(Steam_IAPWS, x=0,T=T)
h_g=ENTHALPY(Steam_IAPWS, x=1,T=T)
h_fg=h_g-h_f

"Some Wrong Solutions with Common Mistakes:"
Q=W1m_steam*h_g "Using h_g"
Q=W2m_steam*4.18*(T2-T1) "Using m*C*DeltaT = Q for water"
Q=W3m_steam*h_f "Using h_f"

4-148 A frictionless piston-cylinder device and a rigid tank contain 2 kmol of an ideal gas at the same temperature, pressure and volume. Now heat is transferred, and the temperature of both systems is raised by 10°C. The amount of extra heat that must be supplied to the gas in the cylinder that is maintained at constant pressure is
(a) 0 kJ (b) 42 kJ (c) 83 kJ (d) 102 kJ (e) 166 kJ

Answer (e) 166 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

"Note that Cp-Cv=R, and thus Q_diff=m*R*dT=N*Ru*dT"
N=2 "kmol"
Ru=8.314 "kJ/kmol.K"
T_change=10
Q_diff=N*Ru*T_change

"Some Wrong Solutions with Common Mistakes:"
W1_Qdiff=0 "Assuming they are the same"
W2_Qdiff=Ru*T_change "Not using mole numbers"
W3_Qdiff=Ru*T_change/N "Dividing by N instead of multiplying"
W4_Qdiff=N*Rair*T_change; Rair=0.287 "using Ru instead of R"

4-149 The specific heat of a material is given in a strange unit to be $C = 3.60$ kJ/kg.°F. The specific heat of this material in the SI units of kJ/kg.°C is

(a) 2.00 kJ/kg.°C   (b) 3.20 kJ/kg.°C   (c) 3.60 kJ/kg.°C   (d) 4.80 kJ/kg.°C   (e) 6.48 kJ/kg.°C

Answer (e) 6.48 kJ/kg.°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

C=3.60 "kJ/kg.F"
C_SI=C*1.8 "kJ/kg.C"

"Some Wrong Solutions with Common Mistakes:"
W1_C=C "Assuming they are the same"
W2_C=C/1.8 "Dividing by 1.8 instead of multiplying"

4-150 A 3-m^3 rigid tank contains nitrogen gas at 500 kPa and 300 K. Now heat is transferred to the nitrogen in the tank and the pressure of nitrogen rises to 800 kPa. The work done during this process is

(a) 500 kJ   (b) 1500 kJ   (c) 0 kJ   (d) 900 kJ   (e) 2400 kJ

Answer (b) 0 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

V=3 "m^3"
P1=500 "kPa"
T1=300 "K"
P2=800 "kPa"
W=0 "since constant volume"

"Some Wrong Solutions with Common Mistakes:"
R=0.297
W1_W=V*(P2-P1) "Using W=V*DELTAP"
W2_W=V*P1
W3_W=V*P2
W4_W=R*T1*ln(P1/P2)

4-151 A 0.8-m^3 cylinder contains nitrogen gas at 600 kPa and 300 K. Now the gas is compressed isothermally to a volume of 0.1 m^3. The work done on the gas during this compression process is
(a) 746 kJ   (b) 0 kJ   (c) 420 kJ   (d) 998 kJ   (e) 1890 kJ

Answer (d) 998 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
R=8.314/28
V1=0.8 "m^3"
V2=0.1 "m^3"
P1=600 "kPa"
T1=300 "K"
P1*V1=m*R*T1
W=m*R*T1* ln(V2/V1) "constant temperature"

"Some Wrong Solutions with Common Mistakes:"
W1_W=R*T1* ln(V2/V1)   "Forgetting m"
W2_W=P1*(V1-V2) "Using V*DeltaP"
P1*V1/T1=P2*V2/T1
W3_W=(V1-V2)*(P1+P2)/2 "Using P_ave*Delta V"
W4_W=P1*V1-P2*V2 "Using W=P1V1-P2V2"
```

4-152 A well-sealed room contains 60 kg of air at 200 kPa and 25°C. Now solar energy enters the room at an average rate of 0.8 kJ/s while a 120-W fan is turned on to circulate the air in the room. If heat transfer through the walls is negligible, the air temperature in the room in 30 min will be
(a) 25.6°C   (b) 49.8°C   (c) 53.4°C   (d) 52.5°C   (e) 63.4°C

Answer (e) 63.4°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
R=0.287 "kJ/kg.K"
Cv=0.718 "kJ/kg.K"
m=60 "kg"
P1=200 "kPa"
T1=25 "C"
Qsol=0.8 "kJ/s"
time=30*60 "s"
Wfan=0.12 "kJ/s"
"Applying energy balance E_in-E_out=dE_system gives"
time*(Wfan+Qsol)=m*Cv*(T2-T1)

"Some Wrong Solutions with Common Mistakes:"
Cp=1.005 "kJ/kg.K"
time*(Wfan+Qsol)=m*Cp*(W1_T2-T1)  "Using Cp instead of Cv "
time*(-Wfan+Qsol)=m*Cv*(W2_T2-T1) "Subtracting Wfan instead of adding"
time*Qsol=m*Cv*(W3_T2-T1) "Ignoring Wfan"
time*(Wfan+Qsol)/60=m*Cv*(W4_T2-T1) "Using min for time instead of s"
```

4-153 A 2-kW baseboard electric resistance heater in a vacant room is turned on and kept on for 15 min. The mass of the air in the room is 75 kg, and the room is tightly sealed so that no air can leak in or out. The temperature rise of air at the end of 15 min is

(a) 8.5°C   (b) 12.4°C   (c) 24.0°C   (d) 33.4°C   (e) 54.8°C

Answer (d) 33.4°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

R=0.287 "kJ/kg.K"
Cv=0.718 "kJ/kg.K"
m=75 "kg"
time=15*60 "s"
W_e=2 "kJ/s"
"Applying energy balance E_in-E_out=dE_system gives"
time*W_e=m*Cv*DELTAT "kJ"

"Some Wrong Solutions with Common Mistakes:"
Cp=1.005 "kJ/kg.K"
time*W_e=m*Cp*W1_DELTAT "Using Cp instead of Cv"
time*W_e/60=m*Cv*W2_DELTAT "Using min for time instead of s"

4-154 A room contains 60 kg of air at 100 kPa and 15°C. The room has a 250-W refrigerator (the refrigerator consumes 250 W of electricity when running), a 120-W TV, a 1-kW electric resistance heater, and a 50-W fan. During a cold winter day, it is observed that the refrigerator, the TV, the fan, and the electric resistance heater are running continuously but the air temperature in the room remains constant. The rate of heat loss from the room that day is

(a) 3312 kJ/h   (b) 4752 kJ/h   (c) 5112 kJ/h   (d) 2952 kJ/h   (e) 4680 kJ/h

Answer (c) 5112 kJ/h

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

R=0.287 "kJ/kg.K"
Cv=0.718 "kJ/kg.K"
m=60 "kg"
P_1=100 "kPa"
T_1=15 "C"
time=30*60 "s"
W_ref=0.250 "kJ/s"
W_TV=0.120 "kJ/s"
W_heater=1 "kJ/s"
W_fan=0.05 "kJ/s"

"Applying energy balance E_in-E_out=dE_system gives E_out=E_in since T=constant and dE=0"
E_gain=W_ref+W_TV+W_heater+W_fan
Q_loss=E_gain*3600 "kJ/h"

"Some Wrong Solutions with Common Mistakes:"

E_gain1=-W_ref+W_TV+W_heater+W_fan "Subtracting Wrefrig instead of adding"
W1_Qloss=E_gain1*3600 "kJ/h"
E_gain2=W_ref+W_TV+W_heater-W_fan "Subtracting Wfan instead of adding"
W2_Qloss=E_gain2*3600 "kJ/h"
E_gain3=-W_ref+W_TV+W_heater-W_fan "Subtracting Wrefrig and Wfan instead of adding"
W3_Qloss=E_gain3*3600 "kJ/h"
E_gain4=W_ref+W_heater+W_fan "Ignoring the TV"
W4_Qloss=E_gain4*3600 "kJ/h"

4-155 A piston-cylinder device contains 5 kg of air at 400 kPa and 30°C. During a quasi-equilibrium isothermal expansion process, 15 kJ of boundary work is done by the system, and 3 kJ of paddle-wheel work is done on the system. The heat transfer during this process is
(a) 12 kJ   (b) 18 kJ   (c) 2.4 kJ   (d) 3.5 kJ   (e) 60 kJ

Answer (a) 12 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

R=0.287 "kJ/kg.K"
Cv=0.718 "kJ/kg.K"
m=5 "kg"
P_1=400 "kPa"
T=30 "C"
Wout_b=15 "kJ"
Win_pw=3 "kJ"
"Noting that T=constant and thus dE_system=0, applying energy balance E_in-E_out=dE_system gives"
Q_in+Win_pw-Wout_b=0

"Some Wrong Solutions with Common Mistakes:"
W1_Qin=Q_in/Cv "Dividing by Cv"
W2_Qin=Win_pw+Wout_b "Adding both quantities"
W3_Qin=Win_pw "Setting it equal to paddle-wheel work"
W4_Qin=Wout_b "Setting it equal to boundaru work"

4-156 A container equipped with a resistance heater and a mixer is initially filled with 3.6 kg of saturated water vapor at 120°C. Now the heater and the mixer are turned on; the steam is compressed, and there is heat loss to the surrounding air. At the end of the process, the temperature and pressure of steam in the container are measured to be 300°C and 0.5 MPa. The net energy transfer to the steam during this process is
(a) 274 kJ   (b) 914 kJ   (c) 1213 kJ   (d) 988 kJ   (e) 1291 kJ

Answer (d) 988 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

m=3.6 "kg"

T1=120 "C"
x1=1 "saturated vapor"
P2=500 "kPa"
T2=300 "C"
u1=INTENERGY(Steam_IAPWS,T=T1,x=x1)
u2=INTENERGY(Steam_IAPWS,T=T2,P=P2)
"Noting that Eout=0 and dU_system=m*(u2-u1), applying energy balance E_in-E_out=dE_system gives"
E_out=0
E_in=m*(u2-u1)

"Some Wrong Solutions with Common Mistakes:"
Cp_steam=1.8723 "kJ/kg.K"
Cv_steam=1.4108 "kJ/kg.K"
W1_Ein=m*Cp_Steam*(T2-T1) "Assuming ideal gas and using Cp"
W2_Ein=m*Cv_steam*(T2-T1) "Assuming ideal gas and using Cv"
W3_Ein=u2-u1 "Not using mass"
h1=ENTHALPY(Steam_IAPWS,T=T1,x=x1)
h2=ENTHALPY(Steam_IAPWS,T=T2,P=P2)
W4_Ein=m*(h2-h1) "Using enthalpy"

4-157 A 6-pack canned drink is to be cooled from 25°C to 3°C. The mass of each canned drink is 0.355 kg. The drinks can be treated as water, and the energy stored in the aluminum can itself is negligible. The amount of heat transfer from the 6 canned drinks is
(a) 33 kJ   (b) 37 kJ   (c) 47 kJ   (d) 196 kJ   (e) 223 kJ

Answer (d) 196 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

C=4.18 "kJ/kg.K"
m=6*0.355 "kg"
T1=25 "C"
T2=3 "C"
DELTAT=T2-T1 "C"
"Applying energy balance E_in-E_out=dE_system and noting that dU_system=m*C*DELTAT gives"
-Q_out=m*C*DELTAT "kJ"

"Some Wrong Solutions with Common Mistakes:"
-W1_Qout=m*C*DELTAT/6 "Using one can only"
-W2_Qout=m*C*(T1+T2) "Adding temperatures instead of subtracting"
-W3_Qout=m*1.0*DELTAT "Using specific heat of air or forgetting specific heat"

4-158 A glass of water with a mass of 0.45 kg at 20°C is to be cooled to 0°C by dropping ice cubes at 0°C into it. The latent heat of fusion of ice is 334 kJ/kg, and the specific heat of water is 4.18 kJ/kg.°C. The amount of ice that needs to be added is

(a) 56 g   (b) 113 g   (c) 124 g   (d) 224 g   (e) 450 g

Answer (b) 113 g

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

C=4.18 "kJ/kg.K"
h_melting=334 "kJ/kg.K"
m_w=0.45 "kg"
T1=20 "C"
T2=0 "C"
DELTAT=T2-T1 "C"
"Noting that there is no energy transfer with the surroundings and the latent heat of melting of ice is transferred form the water, and applying energy balance E_in-E_out=dE_system to ice+water gives"
dE_ice+dE_w=0
dE_ice=m_ice*h_melting
dE_w=m_w*C*DELTAT "kJ"

"Some Wrong Solutions with Common Mistakes:"
W1_mice*h_melting*(T1-T2)+m_w*C*DELTAT=0 "Multiplying h_latent by temperature difference"
W2_mice=m_w "taking mass of water to be equal to the mass of ice"

4-159 A 2-kW electric resistance heater submerged in 5-kg water is turned on and kept on for 10 min. During the process, 300 kJ of heat is lost from the water. The temperature rise of water is

(a) 0.4°C   (b) 43.1°C   (c) 57.4°C   (d) 71.8°C   (e) 180.0°C

Answer (b) 43.1°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

C=4.18 "kJ/kg.K"
m=5 "kg"
Q_loss=300 "kJ"
time=10*60 "s"
W_e=2 "kJ/s"
"Applying energy balance E_in-E_out=dE_system gives"
time*W_e-Q_loss = dU_system
dU_system=m*C*DELTAT "kJ"

"Some Wrong Solutions with Common Mistakes:"
time*W_e = m*C*W1_T "Ignoring heat loss"
time*W_e+Q_loss = m*C*W2_T "Adding heat loss instead of subtracting"
time*W_e-Q_loss = m*1.0*W3_T "Using specific heat of air or not using specific heat"

4-160 3 kg of liquid water initially at 12°C is to be heated to 95°C in a teapot equipped with a 1200 W electric heating element inside. The specific heat of water can be taken to be 4.18 kJ/kg.°C, and the heat loss from the water during heating can be neglected. The time it takes to heat the water to the desired temperature is

(a) 4.8 min   (b) 14.5 min   (c) 6.7 min   (d) 9.0 min   (e) 18.6 min

Answer (b) 14.5 min

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
C=4.18 "kJ/kg.K"
m=3 "kg"
T1=12 "C"
T2=95 "C"
Q_loss=0 "kJ"
W_e=1.2 "kJ/s"
"Applying energy balance E_in-E_out=dE_system gives"
(time*60)*W_e-Q_loss = dU_system  "time in minutes"
dU_system=m*C*(T2-T1) "kJ"

"Some Wrong Solutions with Common Mistakes:"
W1_time*60*W_e-Q_loss = m*C*(T2+T1) "Adding temperatures instead of subtracting"
W2_time*60*W_e-Q_loss = C*(T2-T1) "Not using mass"
```

4-161 An ordinary egg with a mass of 0.1 kg and a specific heat of 3.32 kJ/kg.°C is dropped into boiling water at 95°C. If the initial temperature of the egg is 5°C, the maximum amount of heat transfer to the egg is

(a) 12 kJ   (b) 30 kJ   (c) 24 kJ   (d) 18 kJ   (e) infinity

Answer (b) 30 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
C=3.32 "kJ/kg.K"
m=0.1 "kg"
T1=5 "C"
T2=95 "C"
"Applying energy balance E_in-E_out=dE_system gives"
E_in = dU_system
dU_system=m*C*(T2-T1) "kJ"

"Some Wrong Solutions with Common Mistakes:"
W1_Ein = m*C*T2  "Using T2 only"
W2_Ein=m*(ENTHALPY(Steam_IAPWS,T=T2,x=1)-ENTHALPY(Steam_IAPWS,T=T2,x=0))
"Using h_fg"
```

4-162 An apple with an average mass of 0.18 kg and average specific heat of 3.65 kJ/kg.°C is cooled from 22°C to 5°C. The amount of heat transferred from the apple is
(a) 0.85 kJ   (b) 62.1 kJ   (c) 17.7 kJ   (d) 11.2 kJ   (e) 7.1 kJ

Answer (d) 11.2 kJ

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

C=3.65 "kJ/kg.K"
m=0.18 "kg"
T1=22 "C"
T2=5 "C"
"Applying energy balance E_in-E_out=dE_system gives"
-Q_out = dU_system
dU_system=m*C*(T2-T1) "kJ"

"Some Wrong Solutions with Common Mistakes:"
-W1_Qout =C*(T2-T1) "Not using mass"
-W2_Qout =m*C*(T2+T1) "adding temperatures"

4–163 The specific heat at constant pressure for an ideal gas is given by $c_p = 0.9+(2.7\times10^{-4})T$ (kJ/kg · K) where T is in kelvin. The change in the enthalpy for this ideal gas undergoing a process in which the temperature changes from 27 to 127°C is most nearly
(a) 90 kJ/kg   (b) 92.1 kJ/kg   (c) 99.5 kJ/kg   (d) 108.9 kJ/kg   (e) 105.2 kJ/kg

Answer (c) 99.5 kJ/kg

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

T1=(27+273) [K]
T2=(127+273) [K]
"Performing the necessary integration, we obtain"
DELTAh=0.9*(T2-T1)+2.7E-4/2*(T2^2-T1^2)

4–164 The specific heat at constant volume for an ideal gas is given by $c_v = 0.7 + (2.7 \times 10^{-4})T$ (kJ/kg · K) where T is in kelvin. The change in the enthalpy for this ideal gas undergoing a process in which the temperature changes from 27 to 127°C is most nearly

(a) 70 kJ/kg   (b) 72.1 kJ/kg   (c) 79.5 kJ/kg   (d) 82.1 kJ/kg   (e) 84.0 kJ/kg

Answer (c) 79.5 kJ/kg

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

T1=(27+273) [K]
T2=(127+273) [K]
"Performing the necessary integration, we obtain"
DELTAh=0.7*(T2-T1)+2.7E-4/2*(T2^2-T1^2)

4–165 A piston–cylinder device contains an ideal gas. The gas undergoes two successive cooling processes by rejecting heat to the surroundings. First the gas is cooled at constant pressure until $T_2 = \frac{3}{4}T_1$. Then the piston is held stationary while the gas is further cooled to $T_3 = \frac{1}{2}T_1$, where all temperatures are in K.

1. The ratio of the final volume to the initial volume of the gas is
(a) 0.25   (b) 0.50   (c) 0.67   (d) 0.75   (e) 1.0

Answer (d) 0.75

Solution From the ideal gas equation
$$\frac{V_3}{V_1} = \frac{V_2}{V_1} = \frac{T_2}{T_1} = \frac{3/4T_1}{T_1} = 0.75$$

2. The work done on the gas by the piston is
(a) $RT_1/4$ (b) $c_v T_1/2$ (c) $c_p T_1/2$ (d) $(c_v+c_p)T_1/4$ (e) $c_v(T_1+T_2)/2$

Answer (a) $RT_1/4$

Solution From boundary work relation (per unit mass)
$$w_{b,out} = \int_1^2 P dv = P_1(v_2 - v_1) = R(3/4T_1 - T_1) = \frac{-RT_1}{4} \longrightarrow w_{b,in} = \frac{RT_1}{4}$$

3. The total heat transferred from the gas is
(a) $RT_1/4$ (b) $c_v T_1/2$ (c) $c_p T_1/2$ (d) $(c_v+c_p)T_1/4$ (e) $c_v(T_1+T_3)/2$

Answer (d) $(c_v+c_p)T_1/4$

Solution From an energy balance
$$q_{in} = c_p(T_2 - T_1) + c_v(T_3 - T_2) = c_p(3/4T_1 - T_1) + c_v(1/2T_1 - 3/4T_1) = \frac{-(c_p + c_v)T_1}{4}$$
$$q_{out} = \frac{(c_p + c_v)T_1}{4}$$

4–166 Saturated steam vapor is contained in a piston–cylinder device. While heat is added to the steam, the piston is held stationary, and the pressure and temperature become 1.2 MPa and 700°C, respectively. Additional heat is added to the steam until the temperature rises to 1200°C, and the piston moves to maintain a constant pressure.

1. The initial pressure of the steam is most nearly
(a) 250 kPa   (b) 500 kPa   (c) 750 kPa   (d) 1000 kPa   (e) 1250 kPa

Answer (b) 500 kPa

2. The work done by the steam on the piston is most nearly
(a) 230 kJ/kg   (b) 1100 kJ/kg   (c) 2140 kJ/kg   (d) 2340 kJ/kg   (e) 840 kJ/kg

Answer (a) 230 kJ/kg

3. The total heat transferred to the steam is most nearly
(a) 230 kJ/kg   (b) 1100 kJ/kg   (c) 2140 kJ/kg   (d) 2340 kJ/kg   (e) 840 kJ/kg

Answer (c) 2140 kJ/kg

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
P2=1200 [kPa]
T2=700 [C]
T3=1200 [C]
P3=P2

"1"
v2=volume(steam_iapws, P=P2, T=T2)
v1=v2
P1=pressure(steam_iapws, x=1, v=v1)

"2"
v3=volume(steam_iapws, P=P3, T=T3)
w_b=P2*(v3-v2)

"3"
u1=intenergy(steam_iapws, x=1, v=v1)
u3=intenergy(steam_iapws, P=P3, T=T3)
q=u3-u1+w_b
```

4-167 … 4-180 Design, Essay, and Experiment Problems

4-172 A claim that fruits and vegetables are cooled by 6°C for each percentage point of weight loss as moisture during vacuum cooling is to be evaluated.

Analysis Assuming the fruits and vegetables are cooled from 30ºC and 0ºC, the average heat of vaporization can be taken to be 2466 kJ/kg, which is the value at 15ºC, and the specific heat of products can be taken to be 4 kJ/kg.ºC. Then the vaporization of 0.01 kg water will lower the temperature of 1 kg of produce by 24.66/4 = 6ºC. Therefore, the vacuum cooled products will lose 1 percent moisture for each 6ºC drop in temperature. Thus the claim is **reasonable**.

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