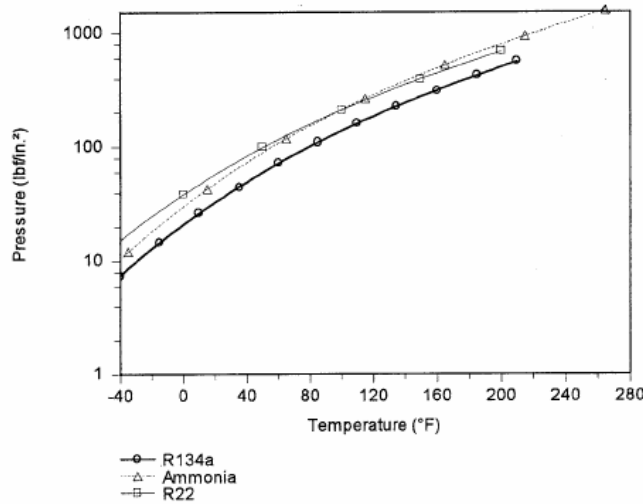
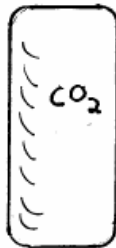


PROBLEM 3.3



PROBLEM 3.1D*



$$T = -40\text{K}$$

$$m = 2\text{ kg}$$

$$V = 0.05\text{ m}^3$$

$$v_f = 0.896 \times 10^{-3} \frac{\text{m}^3}{\text{kg}}$$

$$v_g = 3.824 \times 10^{-2} \frac{\text{m}^3}{\text{kg}}$$

First, find the specific volume

$$v = \frac{V}{m} = \frac{0.05\text{ m}^3}{2\text{ kg}} = 0.025\text{ m}^3/\text{kg}$$

Now, the quality is

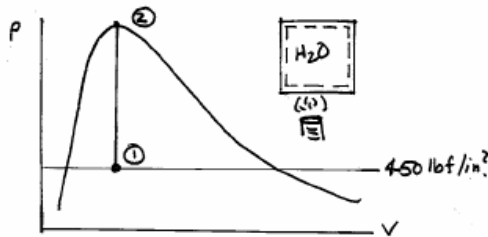
$$x = \frac{v - v_f}{v_g - v_f} = \frac{0.025 - 0.896 \times 10^{-3}}{3.824 \times 10^{-2} - 0.896 \times 10^{-3}}$$

$$= 0.645 \text{ (64.5\%)} \leftarrow x$$

PROBLEM 3.28

KNOWN: A two-phase liquid-vapor mixture is heated at fixed volume from an initial pressure to the critical point.
FIND: Determine the quality at the initial state.

SCHEMATIC & GIVEN DATA:



ASSUMPTIONS: 1. The quantity of water under consideration is the closed system. 2. Volume remains constant.

ANALYSIS: Since volume and mass remain constant, $v_2 = v_1$. From Table A-3E at the critical point, state 2, $v_2 = 0.0505\text{ ft}^3/\text{lb}$. Thus, with $v_2 = v_1$, we have with data from Table A-3E at 450 lb/in.^2

$$v_1 = v_f + x_1 (v_g - v_f) \Rightarrow$$

$$x_1 = \frac{v_1 - v_f}{v_g - v_f} = \frac{(0.0505 - 0.01955)}{1.033 - 0.01955} = 0.0305 \text{ (3.05\%)} \leftarrow x_1$$

PROBLEM 3.39 Water is the substance.

(a) $p = 20 \text{ lbf/in}^2, T = 400^\circ\text{F}$

Table A-4E

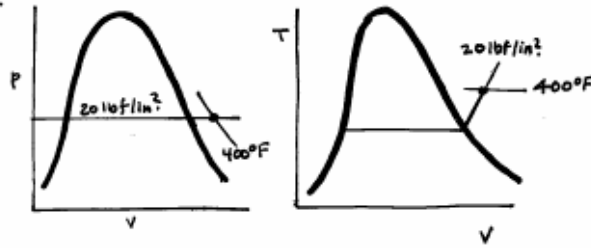
$v = 25.43 \text{ ft}^3/\text{lb}$

$u = 1145.1 \text{ Btu/lb}$

IT Results

$v = 25.43 \text{ ft}^3/\text{lb}$

$u = 1145 \text{ Btu/lb}$



(b) $p = 20 \text{ lbf/in}^2, v = 16 \text{ ft}^3/\text{lb}$

Table A-3E $v_f < v < v_g$

$\Rightarrow T = 227.96^\circ\text{F}$

$x = \frac{v - v_f}{v_g - v_f}$

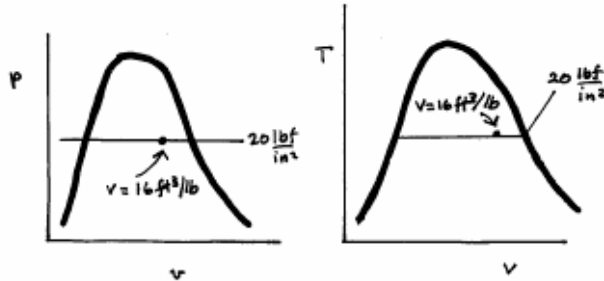
$= \frac{16 - 0.01683}{20.09 - 0.01683}$

$= 0.796$

$\therefore u = u_f + x(u_g - u_f)$

$= 196.19 + 0.796(1082 - 196.19)$

$= 901.29 \text{ Btu/lb}$



IT Results: $T = 228^\circ\text{F}, x = 0.7962, u = 901.3 \text{ Btu/lb}$

(c) $T = 900^\circ\text{F}, p = 170 \text{ lbf/in}^2$

Table A-4E, interpolate at 900°F

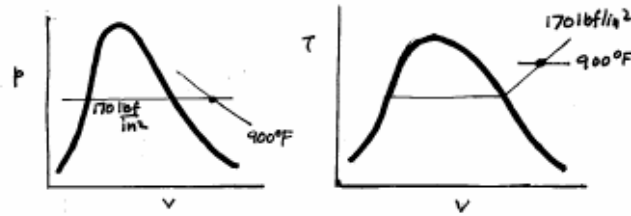
$v = 4.734 \text{ ft}^3/\text{lb}$

$h = 1478.05 \text{ Btu/lb}$

IT Results

$v = 4.718 \text{ ft}^3/\text{lb}$

$h = 1478 \text{ Btu/lb}$



(d) $T = 600^\circ\text{F}, v = 0.6 \text{ ft}^3/\text{lb}$

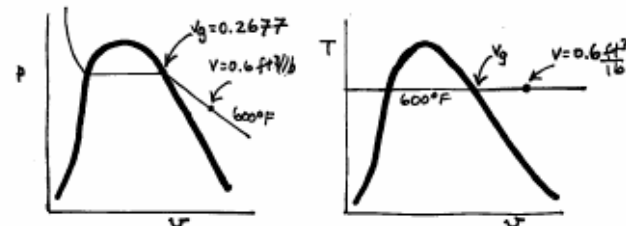
Table A-2E, $v > v_g$ at 600°F .

\Rightarrow Table A-4E. At 600°F the state falls between 800 and 900 lbf/in².

Interpolating,

$p = 885.6 \text{ lbf/in}^2$

$u = 1163.34 \text{ Btu/lb}$



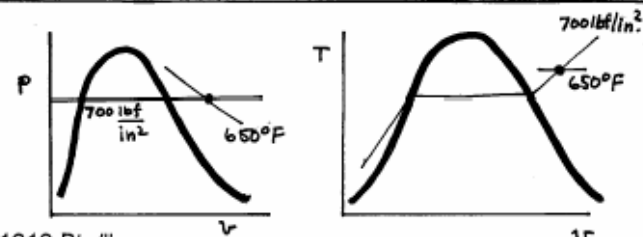
IT Results: $p = 884.3 \text{ lbf/in}^2, u = 1163 \text{ Btu/lb}$

(e) $p = 700 \text{ lbf/in}^2, T = 650^\circ\text{F}$

Table A-4E, interpolation at 700 lbf/in^2

$v = 0.85 \text{ ft}^3/\text{lb}$

$h = 1312.3 \text{ Btu/lb}$



IT Results: $v = 0.852 \text{ ft}^3/\text{lb}, h = 1313 \text{ Btu/lb}$

PROBLEM 13.39 (Contd.)

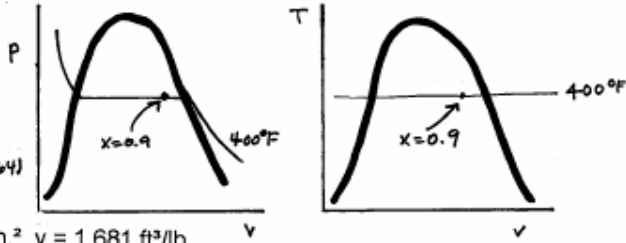
(f) $T = 400^\circ\text{F}$, $x = 90\%$

Table A-2E

$p = 247.1 \text{ lbf/in}^2$

$v = v_f + x v_{fg}$
 $= 0.01864 + .9(1.866 - 0.01864)$
 $= 1.6813 \text{ ft}^3/\text{lb}$

IT Results: $p = 247.1 \text{ lbf/in}^2$, $v = 1.681 \text{ ft}^3/\text{lb}$



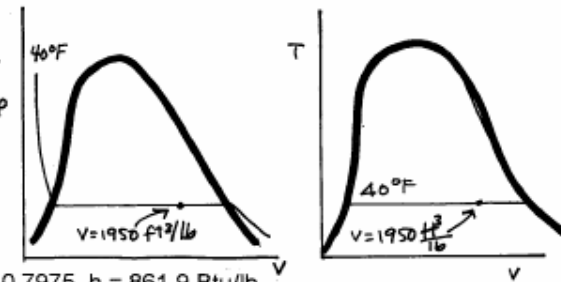
(g) $T = 40^\circ\text{F}$, $v = 1950 \frac{\text{ft}^3}{\text{lb}}$

Table A-2E $v_f < v < v_g$ at 40°F . Thus, $p = 0.1217 \text{ lbf/in}^2$

$x = \frac{v - v_f}{v_g - v_f} = \frac{1950 - 0.016}{2441 - 0.016}$
 $= 0.798$

$h = h_f + x h_{fg}$
 $= 80.2 + 0.798(1070.9)$
 $= 862.6 \text{ Btu/lb}$

IT Results: $p = 0.1217 \text{ lbf/in}^2$, $x = 0.7975$, $h = 861.9 \text{ Btu/lb}$



(h) $p = 600 \text{ lbf/in}^2$, $T = 320^\circ\text{F}$

Table A-3E at 600 lbf/in^2

$T_{\text{sat}} = 486.33^\circ\text{F}$

\Rightarrow liquid state

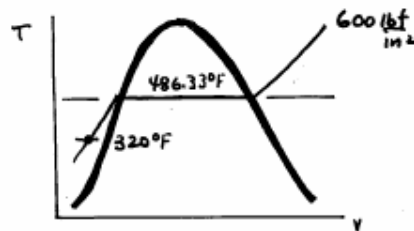
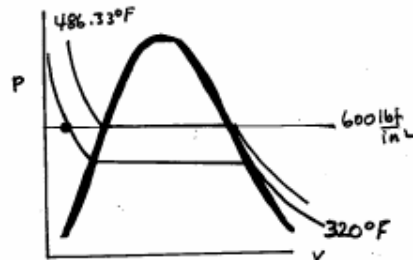
Table A-5E - double interpolation

	$p = 500 \text{ lbf/in}^2$	$p = 1000$
$T = 300^\circ\text{F}$	$v = 0.017416$ $u = 268.92$	0.017379 268.24
$T = 400$	$v = 0.018608$ $u = 373.68$	0.018550 372.55

at 600 lbf/in^2	
300°F	$v = 0.017409$ $u = 268.78$
400°F	$v = 0.018596$ $u = 372.45$

Then, at 600 lbf/in^2 , 320°F

$v = 0.017646 \text{ ft}^3/\text{lb}$
 $u = 289.71 \text{ Btu/lb}$



IT Results

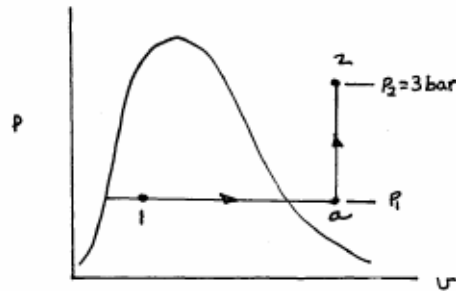
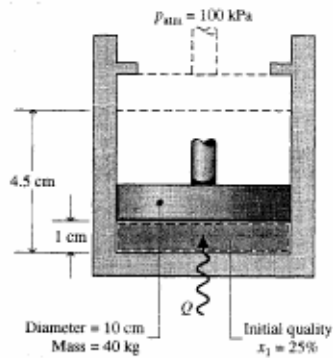
$v = 0.01766 \text{ ft}^3/\text{lb}$
 $u = 288.3 \text{ Btu/lb}$

PROBLEM 3.61

KNOWN: Water contained in a piston-cylinder assembly is heated at constant pressure followed by heating at constant volume.

FIND: Determine the heat transfer.

SCHEMATIC & GIVEN DATA:



ASSUMPTIONS: 1. The water is a closed system. 2. The pressure is constant until the piston hits the stops. 3. Friction between the piston and cylinder wall can be ignored. 4. For the system, $\Delta PE, \Delta KE$ can be ignored. 5. g is constant.

ANALYSIS: To begin, fix the three states located by dots on the $p-v$ diagram. State 1 is fixed by $x_1 = 25\%$ and p_1 , which is found from a force balance on the piston: The force exerted by the water on the lower face of the piston equals the piston weight plus the force exerted on the top face by the atmosphere:

$$p_1 A = m_{\text{pist}} g + p_{\text{atm}} A, \quad A = \pi D_{\text{pist}}^2 / 4$$

\Rightarrow

$$p_1 = \frac{m_{\text{pist}} g}{A} + p_{\text{atm}} = \frac{(40 \text{ kg})(9.81 \text{ m/s}^2)}{\frac{\pi}{4} (0.1 \text{ m})^2} \left| \frac{1 \text{ N}}{\text{kg} \cdot \text{m/s}^2} \right| \left| \frac{\text{bar}}{10^5 \text{ N/m}^2} \right| + (100 \text{ kPa}) \left| \frac{1 \text{ bar}}{10^5 \text{ kPa}} \right|$$

$$= 1.5 \text{ bar}$$

State a is fixed by $p_a = p_1 = 1.5 \text{ bar}$ and the specific volume, v_a . From the given geometry, $v_a = 4.5 v_1$ or $v_a = 4.5 v_1$, where

$$v_1 = v_{f1} + x_1 (v_{g1} - v_{f1}) = \frac{1.0528}{10^3} + 0.25 (1.159 - \frac{1.0528}{10^3}) = 0.29054 \text{ m}^3/\text{kg}$$

$$\Rightarrow v_a = 4.5 (0.29054) = 1.3074 \text{ m}^3/\text{kg}$$

Since $v_a > v_g(1.5 \text{ bar})$, state a falls in the superheated vapor region, as shown in the $p-v$ diagram. State 2 is fixed by $v_2 = v_a$ and $p_2 = 3 \text{ bar}$.

The total mass of water is

$$m = \frac{V}{v_1} = \frac{\pi/4 (0.1 \text{ m})^2 (0.01 \text{ m})}{0.29054 \text{ m}^3/\text{kg}} = 2.703 \times 10^{-4} \text{ kg}$$

PROBLEM 3.61 (Contd.)

Since there is no work associated with the constant volume portion of the process, the total work is obtained as the water undergoes the constant pressure expansion from 1 to a:

$$W = \int_1^a p dV = p[V_a - V_1] = p[V_2 - V_1] = mp(u_2 - u_1)$$

That is, with $v_2 = 4.5v_1$,

$$W = (2.703 \times 10^{-4} \text{ kg})(1.5 \text{ bar}) \left| \frac{10^5 \text{ N/m}^2}{1 \text{ bar}} \right| (3.5) \left(0.29054 \frac{\text{m}^3}{\text{kg}} \right) \left| \frac{1 \text{ J}}{1 \text{ N}\cdot\text{m}} \right|$$

$$= 41.23 \text{ J}$$

An energy balance reads

$$\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q - W$$

$$\Rightarrow Q = \Delta U + W$$

$$= m(u_2 - u_1) + W$$

where

$$u_1 = u_f + x_1(u_g - u_f)$$

$$= 466.94 + 0.25(2519.7 - 466.94) = 980.13 \text{ kJ/kg}$$

To find u_2 , interpolate in Table A-4 at 3 bar using v_2 : $u_2 = 3263.53 \text{ kJ/kg}$. Then

$$Q = (2.703 \times 10^{-4} \text{ kg}) \left(3263.53 - 980.13 \right) \frac{\text{kJ}}{\text{kg}} \left| \frac{10^3 \text{ J}}{\text{kJ}} \right| + 41.23 \text{ J}$$

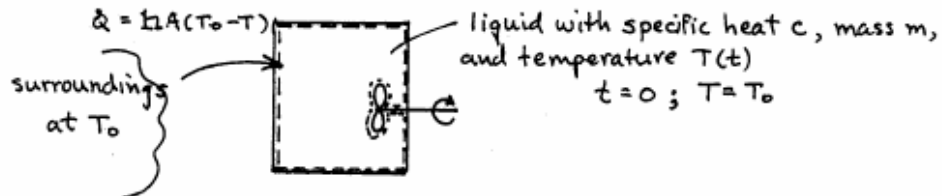
$$= 658.43 \text{ J}$$

PROBLEM 3.12

KNOWN: A liquid in a rigid tank is stirred by a paddle wheel and experiences energy transfer by heat with its surroundings.

FIND: Obtain a differential equation for temperature T in terms of time t and relevant parameters. Solve for $T(t)$.

Schematic & Given Data:



ASSUMPTIONS: (1) The liquid is the closed system. (2) The liquid behaves as an incompressible substance with constant specific heat c . (3) The energy transfer from the paddle wheel to the system occurs at a constant rate. (4) There are no changes in kinetic or potential energy.

ANALYSIS: The energy rate balance is

$$\frac{dKE}{dt} + \frac{dPE}{dt} + \frac{dU}{dt} = \dot{Q} - \dot{W}$$

with $dU/dt = mc \, dT/dt$ and $\dot{Q} = hA(T_0 - T)$

$$mc \frac{dT}{dt} = hA(T_0 - T) - \dot{W} \quad \leftarrow \text{differential equation}$$

To solve, let $\theta = T_0 - T$; $dT = -d\theta$. Thus

$$\frac{d\theta}{dt} + \left(\frac{hA}{mc}\right)\theta - \frac{\dot{W}}{mc} = 0$$

The solution of this differential equation is of the form

$$\theta(t) = c_1 \exp\left[-\left(\frac{hA}{mc}\right)t\right] + \frac{\dot{W}}{hA}$$

at $t=0$, $T = T_0 \Rightarrow \theta = 0$. Thus $c_1 = -\dot{W}/hA$, so

$$\theta(t) = \frac{\dot{W}}{hA} \left\{ 1 - \exp\left[-\left(\frac{hA}{mc}\right)t\right] \right\}$$

$$\textcircled{1} \textcircled{2} \quad \text{or} \quad T(t) = T_0 - \frac{\dot{W}}{hA} \left\{ 1 - \exp\left[-\left(\frac{hA}{mc}\right)t\right] \right\} \quad \leftarrow T(t)$$

1. The solution can be verified by direct substitution into the differential equation. 2. The solution satisfies the initial condition that $T(0) = T_0$.

PROBLEM 3.84

(a) Water vapor at 2000 lbf/in², 700°F

From Table A-4E: $v_{table} = 0.249 \text{ ft}^3/\text{lb}$

Ideal gas model:

$$v_{ideal\ gas} = \frac{\left(\frac{1545}{18.02} \frac{\text{ft}\cdot\text{lbf}}{\text{lb}\cdot^\circ\text{R}}\right)(1160^\circ\text{R})}{(2000 \text{ lbf/in}^2) \left|\frac{144 \text{ in}^2}{1 \text{ ft}^2}\right|} = 0.3453 \text{ ft}^3/\text{lb}$$

$$\% \text{ error} = \frac{0.3453 - 0.249}{0.249} \times 100 = 38.7\% \leftarrow (a)$$

(b) Water vapor at 1 lbf/in², 200°F

Table A-4E: $v_{table} = 392.5 \text{ ft}^3/\text{lb}$

Ideal gas model:

$$v_{ideal\ gas} = \frac{\left(\frac{1545}{18.02}\right)(660)}{(1) \left|\frac{144}{1}\right|} = 393.0 \text{ ft}^3/\text{lb}$$

$$\% \text{ error} = \frac{393.0 - 392.5}{392.5} \times 100 = 0.13\% \leftarrow (b)$$

(c) Ammonia at 60 lbf/in², 160°F

Table A-15E: $v_{table} = 6.3458 \text{ ft}^3/\text{lb}$

Ideal gas model:

$$v_{ideal\ gas} = \frac{\left(\frac{1545}{17.04}\right)(620)}{(60)(144)} = 6.5063 \text{ ft}^3/\text{lb}$$

$$\% \text{ error} = \frac{6.5063 - 6.3458}{6.3458} \times 100 = 2.53\% \leftarrow (c)$$

(d) Air at 1 atm, 2000°R

$$P_R = P/P_c = 1 \text{ atm}/37.2 \text{ atm} = 0.027 \left. \begin{array}{l} \text{Fig. A-2} \\ Z \approx 1.0 \end{array} \right\}$$

$$T_R = T/T_c = 2000^\circ\text{R}/239^\circ\text{R} = 8.37$$

Ideal gas $\leftarrow (d)$

(e) R-22 at 300 lbf/in², 140°F

Table A-9E: $v_{table} = 0.1849 \text{ ft}^3/\text{lb}$

Ideal gas model:

$$v_{ideal\ gas} = \frac{\left(\frac{1545}{86.48}\right)(600)}{(300) \left|\frac{144}{1}\right|} = 0.2481 \text{ ft}^3/\text{lb}$$

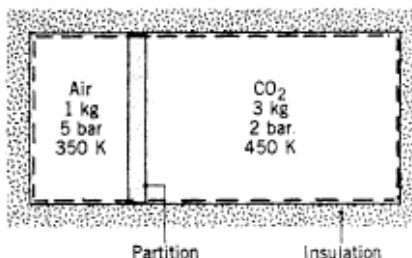
$$\% \text{ error} = \frac{0.2481 - 0.1849}{0.1849} \times 100 = 34.2\% \leftarrow (e)$$

PROBLEM 3.96

KNOWN: Air and carbon dioxide are confined to opposite sides of a rigid, wall-insulated container. The partition moves and allows conduction from one gas to the other until equilibrium is achieved.

FIND: Determine the final temperature and pressure.

SCHEMATIC & GIVEN DATA: **



- ASSUMPTIONS:** (1) The contents of the container form a closed system. (2) The air and CO₂ behaves as ideal gases with constant specific heats. (3) The system is isolated, so $Q=0$ and $W=0$. (4) There is no energy stored in the partition. (5) Kinetic and potential energy effects are negligible.

ANALYSIS: To determine the final temperature, begin with the energy balance

$$\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = \cancel{Q} - \cancel{W}$$

or, with $\Delta U = m_{air} \Delta u_{air} + m_{CO_2} \Delta u_{CO_2}$ and using Eq. 3.50

$$\textcircled{1} \quad m_{air} c_{v,air} (T_2 - T_{1,air}) + m_{CO_2} c_{v,CO_2} (T_2 - T_{1,CO_2}) = 0$$

Solving for T_2

$$T_2 = \frac{m_{air} c_{v,air} T_{1,air} + m_{CO_2} c_{v,CO_2} T_{1,CO_2}}{m_{air} c_{v,air} + m_{CO_2} c_{v,CO_2}}$$

The specific heats are evaluated using data from Table A-20 at a mean temperature of 400K; $c_{v,air} = 0.726$ kJ/kg·K and $c_{v,CO_2} = 0.750$ kJ/kg·K. Thus, the final temperature is

$$T_2 = \frac{(1 \text{ kg})(0.726 \text{ kJ/kg}\cdot\text{K})(350 \text{ K}) + (3)(.750)(450)}{(1 \text{ kg})(0.726 \text{ kJ/kg}\cdot\text{K}) + (3)(.750)} = 425.6 \text{ K} \leftarrow T_2$$

Next, to find the final pressure, the total volume is needed. The initial volume of the air is

$$V_{1,air} = \frac{m_{air} R_{air} T_{1,air}}{P_{1,air}} = \frac{(1 \text{ kg}) \left(\frac{8.314 \text{ kJ}}{28.97 \text{ kg}\cdot\text{K}} \right) (350 \text{ K})}{(5 \text{ bar})} \left| \frac{1 \text{ bar}}{10^5 \text{ N/m}^2} \right| \left| \frac{10^3 \text{ N}\cdot\text{m}}{1 \text{ kJ}} \right| = 0.201 \text{ m}^3$$

PROBLEM 3.96

similarly for the carbon dioxide

$$V_{1, \text{CO}_2} = \frac{m_{\text{CO}_2} R_{\text{CO}_2} T_{1, \text{CO}_2}}{P_{1, \text{CO}_2}} = \frac{(3) \left(\frac{8.314}{44.01} \right) (450)}{(2)} \left| \frac{10^3}{10^5} \right|$$

$$= 1.275 \text{ m}^3$$

Thus $V_{\text{tot}} = 0.201 \text{ m}^3 + 1.275 \text{ m}^3 = 1.476 \text{ m}^3$

Now, at the final state

$$P_2 = \frac{n_{\text{tot}} \bar{R} T_2}{V_{\text{tot}}} = \frac{(n_{\text{air}} + n_{\text{CO}_2}) \bar{R} T_2}{V_{\text{tot}}}$$

With $n = m/M$

$$P_2 = \frac{(m_{\text{air}}/M_{\text{air}} + m_{\text{CO}_2}/M_{\text{CO}_2}) \bar{R} T_2}{V_{\text{tot}}}$$

$$= \frac{\left(\frac{1 \text{ kg}}{28.97 \text{ kg/kmol}} + \frac{3}{44.01} \right) \left(8.314 \frac{\text{kJ}}{\text{kmol}\cdot\text{K}} \right) (425.6 \text{ K})}{(1.476 \text{ m}^3)} \left| \frac{10^3 \text{ N}\cdot\text{m}}{1 \text{ kJ}} \right| \left| \frac{1 \text{ bar}}{10^5 \text{ N/m}^2} \right|$$

$$= 2.462 \text{ bar} \longleftarrow P_2$$

1. The assumption of constant specific heats facilitates the determination of T_2 . The assumption is reasonable for the relatively small temperature range in this problem.

PROBLEM 3.109

- (a) For an adiabatic process with negligible effects of kinetic and potential energy

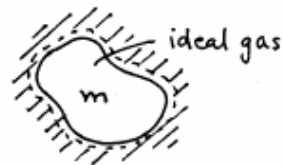
$$\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = \cancel{Q} - W$$

Since the specific heats are constant

$$W = m c_v (T_1 - T_2)$$

or, using Eq. 3.47b, $c_v = R/(k-1)$, so

$$W = \frac{m R (T_2 - T_1)}{1-k} \longleftarrow (a)$$



- (b) For a polytropic process

$$W = \int_{V_1}^{V_2} p dV = \int_{V_1}^{V_2} \frac{\text{const}}{V^n} dV = \frac{P_2 V_2 - P_1 V_1}{1-n}$$

Introducing $PV = mRT$ and letting n be the specific heat ratio k

$$W = \frac{m R (T_2 - T_1)}{1-k}$$

This result is identical to the result of part (a). Thus, for an ideal gas with constant specific heats, the polytropic process $PV^k = \text{constant}$ corresponds to an adiabatic process. $\longleftarrow (b)$