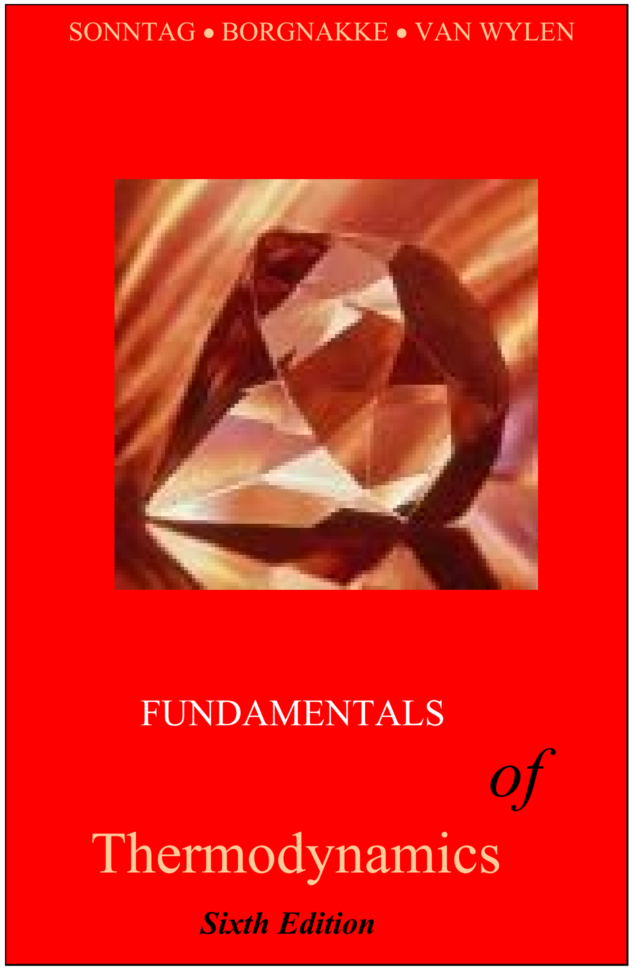
SOLUTION MANUAL
ENGLISH UNIT PROBLEMS
CHAPTER 5



CHAPTER 5

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New	5th	SI	New	5th	SI	New	5th	SI
139	new	1	154	new	44	169	121	95
140	new	-	155	112	50	170	new	89 a
141	new	7	156	115	48	171	125	101
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143	new	12	158	110	126	173	129	112
144	new	17	159	109	64	174	123	107
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147	103	21	162	118	128	177	131	114mod
148	104 mod	32	163	124	85	178	132	115
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150	104 mod	-	165	new	77	180	new	125
151	107	37	166	120	76	181	136	117
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Concept Problems

5.139E

What is 1 cal in english units, what is 1 Btu in ft-lbf?

Look in Table A.1 for the conversion factors under energy

1 Btu = **778.1693 lbf-ft**

$$1 \text{ cal} = 4.1868 \text{ J} = \frac{4.1868}{1055} \text{ Btu} = \mathbf{0.00397 \text{ Btu}} = \mathbf{3.088 \text{ lbf-ft}}$$

5.140E

Work as F Δx has units of lbf-ft, what is that in Btu?

Look in Table A.1 for the conversion factors under energy

$$1 \text{ lbf-ft} = 1.28507 \times 10^{-3} \text{ Btu}$$

5.141E

A 2500 lbm car is accelerated from 25 mi/h to 40 mi/h. How much work is that?

The work input is the increase in kinetic energy.

$$E_2 - E_1 = (1/2)m\left[\mathbf{V}_2^2 - \mathbf{V}_1^2\right] = {}_1W_2$$

$$= 0.5 \times 2500 \text{ lbm } [40^2 - 25^2] \left(\frac{\text{mi}}{\text{h}}\right)^2$$

$$= 1250 \text{ [} 1600 - 625 \text{] lbm} \left(\frac{1609.3 \times 3.28084 \text{ ft}}{3600 \text{ s}}\right)^2 \frac{1 \text{ lbf}}{32.174 \text{ lbm ft/s}^2}$$

$$= \mathbf{2\ 621\ 523 \text{ lbf-ft} = 3369 \text{ Btu}}$$

5.142E

A crane use 7000 Btu/h to raise a 200 lbm box 60 ft. How much time does it take?

$$\text{Power} = \dot{W} = F\mathbf{V} = mg\mathbf{V} = mg\frac{L}{t}$$

$$F = mg = 200\,\frac{32.174}{32.174}\text{ lbf} = 200\text{ lbf}$$

$$t = \frac{FL}{\dot{W}} = \frac{200\text{ lbf} \times 60\text{ ft}}{7000\text{ Btu/h}} = \frac{200 \times 60 \times 3600}{7000 \times 778.17}\text{ s}$$

$$= \mathbf{7.9\ s}$$

Recall Eq. on page 20: 1 lbf = 32.174 lbm ft/s^2, 1 Btu = 778.17 lbf-ft (A.1)

5.143E

I have 4 lbm of liquid water at 70 F, 15 psia. I now add 20 Btu of energy at a constant pressure. How hot does it get if it is heated? How fast does it move if it is pushed by a constant horizontal force? How high does it go if it is raised straight up?

a) Heat at 100 kPa.
Energy equation:

$$E_2 - E_1 = {}_1Q_2 - {}_1W_2 = {}_1Q_2 - P(V_2 - V_1) = H_2 - H_1 = m(h_2 - h_1)$$

$$h_2 = h_1 + {}_1Q_2/m = 38.09 + 20/4 = 43.09 \text{ Btu/lbm}$$

Back interpolate in Table F.7.1: $T_2 = \mathbf{75\ F}$

(We could also have used $\Delta T = {}_1Q_2/mC = 20 / (4\times1.00) = 5$ F)

b) Push at constant P. It gains kinetic energy.

$$0.5\ m\ \mathbf{V}_2^2 = {}_1W_2$$

$$\mathbf{V}_2 = \sqrt{2\ {}_1W_2/m} = \sqrt{2 \times 20 \times 778.17 \text{ lbf-ft}/4 \text{ lbm}}$$

$$= \sqrt{2 \times 20 \times 778.17 \times 32.174 \text{ lbm-(ft/s)}^2 /4 \text{ lbm}} = \mathbf{500\ ft/s}$$

c) Raised in gravitational field

$$m\ g\ Z_2 = {}_1W_2$$

$$Z_2 = {}_1W_2/m\ g = \frac{20 \times 778.17 \text{ lbf-ft}}{4 \text{ lbm} \times 32.174 \text{ ft/s}^2} \times 32.174 \frac{\text{lbm-ft/s}^2}{\text{lbf}} = \mathbf{3891\ ft}$$

5.144E

Air is heated from 540 R to 640 R at V = C. Find ${}_1q_2$? What if from 2400 to 2500 R?

Process: V = C → ${}_1W_2 = Ø$

Energy Eq.: $u_2 - u_1 = {}_1q_2 - 0$ → ${}_1q_2 = u_2 - u_1$

Read the u-values from Table F.5

a) ${}_1q_2 = u_2 - u_1 = 109.34 - 92.16 =$ **17.18 Btu/lbm**

b) ${}_1q_2 = u_2 - u_1 = 474.33 - 452.64 =$ **21.7 Btu/lbm**

case a) $C_v \approx 17.18/100 = 0.172$ Btu/lbm R, see F.4

case b) $C_v \approx 21.7/100 = 0.217$ Btu/lbm R (26 % higher)

Kinetic and Potential Energy

5.145E

Airplane takeoff from an aircraft carrier is assisted by a steam driven piston/cylin-der with an average pressure of 200 psia. A 38 500 lbm airplane should be accelerated from zero to a speed of 100 ft/s with 30% of the energy coming from the steam piston. Find the needed piston displacement volume.

Solution: C.V. Airplane.

No change in internal or potential energy; only kinetic energy is changed.

$$E_2 - E_1 = m\,(1/2)\,(\mathbf{V}_2^2 - 0) = 38\,500 \text{ lbm} \times (1/2) \times 100^2 \text{ (ft/s)}^2$$

$$= 192\,500\,000 \text{ lbm-(ft/s)}^2 = 5\,983\,092 \text{ lbf-ft}$$

The work supplied by the piston is 30% of the energy increase.

$$W = \int P\,dV = P_{avg}\ \Delta V = 0.30\,(E_2 - E_1)$$

$$= 0.30 \times 5\,983\,092 \text{ lbf-ft} = 1\,794\,928 \text{ lbf-ft}$$

$$\Delta V = \frac{W}{P_{avg}} = \frac{1\,794\,928}{200}\,\frac{\text{lbf-ft}}{144 \text{ lbf/ft}^2} = \mathbf{62.3\ ft^3}$$

5.146E

A hydraulic hoist raises a 3650 lbm car 6 ft in an auto repair shop. The hydraulic pump has a constant pressure of 100 lbf/in.^{2} on its piston. What is the increase in potential energy of the car and how much volume should the pump displace to deliver that amount of work?

Solution: C.V. Car.

No change in kinetic or internal energy of the car, neglect hoist mass.

$$E_2 - E_1 = PE_2 - PE_1 = mg\,(Z_2 - Z_1) = \frac{3650 \times 32.174 \times 6}{32.174} = 21\,900 \text{ lbf-ft}$$

The increase in potential energy is work into car from pump at constant P.

$$W = E_2 - E_1 = \int P\, dV = P\, \Delta V \qquad \Rightarrow$$

$$\Delta V = \frac{E_2 - E_1}{P} = \frac{21\,900}{100 \times 144} = \mathbf{1.52\ ft^3}$$

5.147E

A piston motion moves a 50 lbm hammerhead vertically down 3 ft from rest to a velocity of 150 ft/s in a stamping machine. What is the change in total energy of the hammerhead?

Solution: C.V. Hammerhead

The hammerhead does not change internal energy i.e. same P,T

$$E_2 - E_1 = m(u_2 - u_1) + m(\frac{1}{2}V_2^2 - 0) + mg\,(h_2 - 0)$$

$$= 0 + [\ 50 \times (1/2) \times 150^2 + 50 \times 32.174 \times (-3)] \,/\, 32.174$$

$$= [562500 - 4826]/32.174 = 17\ 333 \text{ lbf-ft}$$

$$= (\frac{17\ 333}{778}) \text{ Btu} = \mathbf{22.28\ Btu}$$

Properties General Tables

5.148E

Find the missing properties and give the phase of the substance.

a. H_2O u = 1000 Btu/lbm, T = 270 F h = ? v = ? x = ?

b. H_2O u = 450 Btu/lbm, P = 1500 lbf/in.^{2} T = ? x = ? v = ?

c. R-22 T = 30 F, P = 75 lbf/in.^{2} h = ? x = ?

Solution:

a) Table F.7.1: $u_f < u < u_g$ => 2-phase mixture of liquid and vapor

$x = (u - u_f)/ u_{fg} = (1000 - 238.81)/854.14 = \mathbf{0.8912}$

$v = v_f + x\, v_{fg} = 0.01717 + 0.8912 \times 10.0483 = \mathbf{8.972\ ft^3/lbm}$

$h = h_f + x\, h_{fg} = 238.95 + 0.8912 \times 931.95 = \mathbf{1069.5\ Btu/lbm}$

$(= 1000 + 41.848 \times 8.972 \times 144/778)$

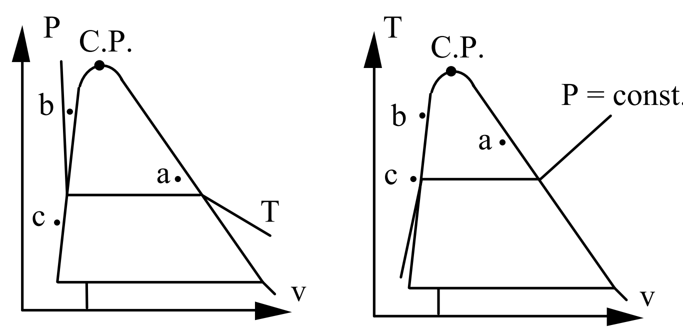
b) Table F.7.1: $u < u_f$ so compressed liquid B.1.3, x = **undefined**

T = **471.8 F**, v = **0.019689 ft^3/lbm**

c) Table F.9.1: P > Psat => x = **undef**, **compr. liquid**

Approximate as saturated liquid at same T, $h \cong h_f$ = **18.61 Btu/lbm**

States shown are placed relative to the two-phase region, not to each other.



5.149E

Find the missing properties among (P, T, v, u, h) together with x, if applicable, and give the phase of the substance.

a. R-22 $T = 50$ F, $u = 85$ Btu/lbm

b. H_2O $T = 600$ F, $h = 1322$ Btu/lbm

c. R-22 $P = 150$ lbf/in.^{2}, $h = 115.5$ Btu/lbm

Solution:

a) Table F.9.1: $u < u_g$ => L+V mixture, $P = \mathbf{98.727\ lbf/in^2}$

$x = (85 - 24.04)/ 74.75 = \mathbf{0.8155}$

$v = 0.01282 + 0.8155 \times 0.5432 = \mathbf{0.4558\ ft^3/lbm}$

$h = 24.27 + 0.8155 \times 84.68 = \mathbf{93.33\ Btu/lbm}$

b) Table F.7.1: $h > h_g$ => superheated vapor follow 600 F in F.7.2

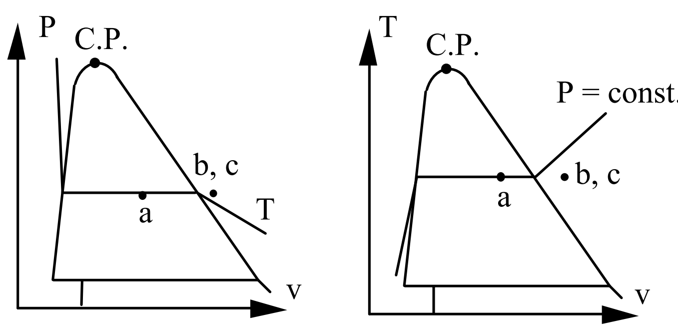
$P \cong \mathbf{200\ lbf/in^2}$; $v = \mathbf{3.058\ ft^3/lbm}$; $u = \mathbf{1208.9\ Btu/lbm}$

c) Table F.9.1: $h > h_g$ => superheated vapor so in F.9.2

$T \cong \mathbf{100\ F}$; $v = \mathbf{0.3953\ ft^3/lbm}$

$$u = h - Pv = 115.5 - 150 \times 0.3953 \times \frac{144}{778} = \mathbf{104.5\ Btu/lbm}$$

States shown are placed relative to the two-phase region, not to each other.



5.150E

Find the missing properties and give the phase of the substance.

a.	R-134a	$T = 140$ F, $h = 185$ Btu/lbm	$v = ?$ $x = ?$
b.	NH_3	$T = 170$ F, $P = 60$ lbf/in.^{2}	$u = ?$ $v = ?$ $x = ?$
c.	R-134a	$T = 100$ F, $u = 175$ Btu/lbm	

Solution:

a) Table F.10.1: h > hg => x = **undef**, **superheated vapor** F.10.2,

find it at given T between saturated 243.9 psi and 200 psi to match h:

$$v \cong 0.1836 + (0.2459 - 0.1836) \times \frac{185 - 183.63}{186.82 - 183.63} = \mathbf{0.2104\ ft^3/lbm}$$

$$P \cong 243.93 + (200 - 243.93) \times \frac{185 - 183.63}{186.82 - 183.63} = \mathbf{225\ lbf/in^2}$$

b) Table F.8.1: $P < P_{sat}$ ⇒ x = **undef.** **superheated vapor** F.8.2,

$v = (6.3456 + 6.5694)/\ 2 =$ **6.457 ft^3/lbm**

$u = h - Pv = (1/2)(694.59 + 705.64) – 60 \times 6.4575 \times (144/778)$

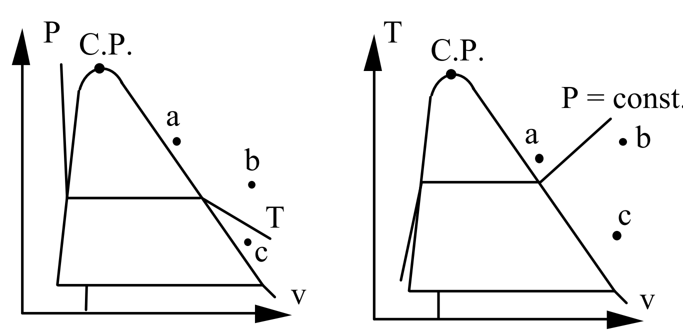
$= 700.115 – 71.71 =$ **628.405 Btu/lbm**

c) Table F.10.1:: $u > u_g$ => **sup. vapor,** calculate u at some P to end with

P ≈ **55 lbf/in^2** ; v ≈ **0.999 ft^3/lbm;** h = **185.2 Btu/lbm**

This is a double linear interpolation

States shown are placed relative to the two-phase region, not to each other.



Simple Processes

5.151E

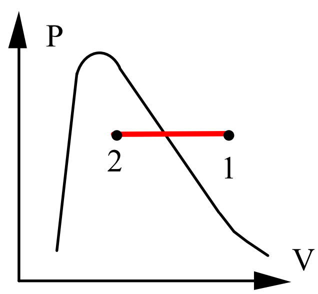
A cylinder fitted with a frictionless piston contains 4 lbm of superheated refrigerant R-134a vapor at 400 lbf/in.^{2}, 200 F. The cylinder is now cooled so the R-134a remains at constant pressure until it reaches a quality of 75%. Calculate the heat transfer in the process.

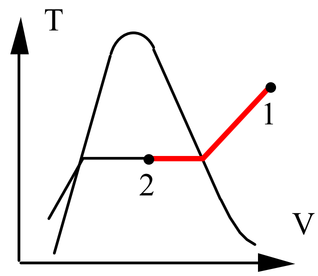
Solution:

C.V.: R-134a $\quad m_2 = m_1 = m;$

Energy Eq.5.11 $\quad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P = const. $\Rightarrow {}_1W_2 = \int PdV = P\Delta V = P(V_2 - V_1) = Pm(v_2 - v_1)$





State 1: Table F.10.2 $\quad h_1 = 192.92$ Btu/lbm

State 2: Table F.10.1 $\quad h_2 = 140.62 + 0.75 \times 43.74 = 173.425$ Btu/lbm

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(u_2 - u_1) + Pm(v_2 - v_1) = m(h_2 - h_1)$$

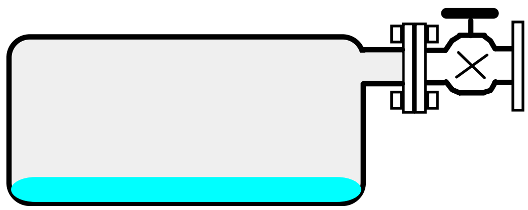
$$= 4 \times (173.425 - 192.92) = \mathbf{-77.98\ Btu}$$

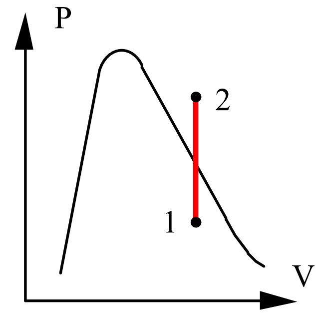
5.152E

Ammonia at 30 F, quality 60% is contained in a rigid 8-ft^3 tank. The tank and ammonia are now heated to a final pressure of 150 lbf/in.^{2}. Determine the heat transfer for the process.

Solution:

C.V.: NH_3





Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: Constant volume $\Rightarrow$ $v_2 = v_1$ & ${}_1W_2 = 0$

State 1: Table F.8.1 two-phase state.

$v_1 = 0.02502 + 0.6 \times 4.7978 = 2.904$ ft^3/lbm

$u_1 = 75.06 + 0.6 \times 491.17 = 369.75$ Btu/lbm

$m = V/v_1 = 8/2.904 = 2.755$ lbm

State 2: P_2, $v_2 = v_1$ $\Rightarrow$ $T_2 \cong 258$ F

$u_2 = h_2 - P_2v_2 = 742.03 - 150 \times 2.904 \times 144/778 = 661.42$ Btu/lbm

${}_1Q_2 = 2.755 \times (661.42 - 369.75) =$ **803.6 Btu**

5.153E

Water in a 6-ft^3 closed, rigid tank is at 200 F, 90% quality. The tank is then cooled to 20 F. Calculate the heat transfer during the process.

Solution:

C.V.: Water in tank. $m_2 = m_1$; $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: V = constant, $v_2 = v_1$, ${}_1W_2 = 0$

State 1: $v_1 = 0.01663 + 0.9 \times 33.6146 = 30.27$ ft^3/lbm

$u_1 = 168.03 + 0.9 \times 906.15 = 983.6$ Btu/lbm

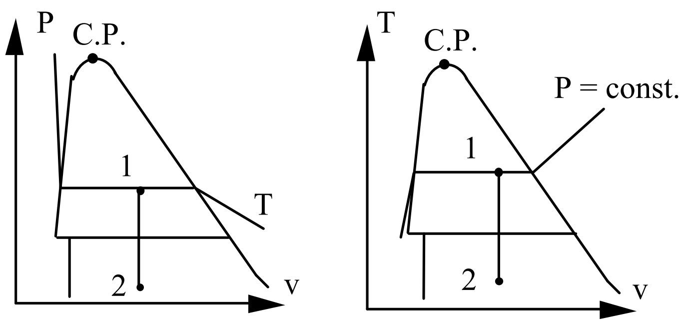
State 2: T_2, $v_2 = v_1$ $\Rightarrow$ mix of sat. solid + vap. Table C.8.4

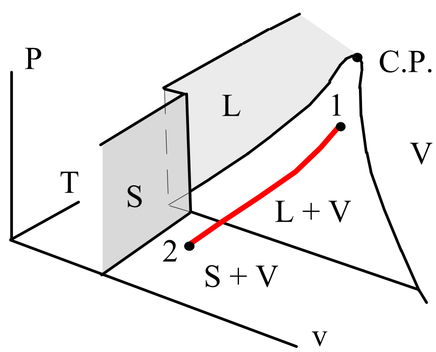
$v_2 = 30.27 = 0.01744 + x_2 \times 5655$ => $x_2 = 0.00535$

$u_2 = -149.31 + 0.00535 \times 1166.5 = -143.07$ Btu/lbm

$m = V/v_1 = 6 / 30.27 = 0.198$ lbm

${}_1Q_2 = m(u_2 - u_1) = 0.198\ (-143.07 - 983.6) =$ **-223 Btu**





5.154E

A constant pressure piston/cylinder has 2 lbm water at 1100 F and 2.26 ft^3. It is now cooled to occupy 1/10 of the original volume. Find the heat transfer in the process.

C.V.: Water $m_2 = m_1 = m$;

Energy Eq.5.11 $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P = const. $\Rightarrow {}_1W_2 = \int P dV = P\Delta V = P(V_2 - V_1) = Pm(v_2 - v_1)$

State 1: Table F.7.2 (T, $v_1 = V/m = 2.26/2 = 1.13$ ft^3/lbm)

$P_1 = 800$ psia, $h_1 = 1567.81$ Btu/lbm

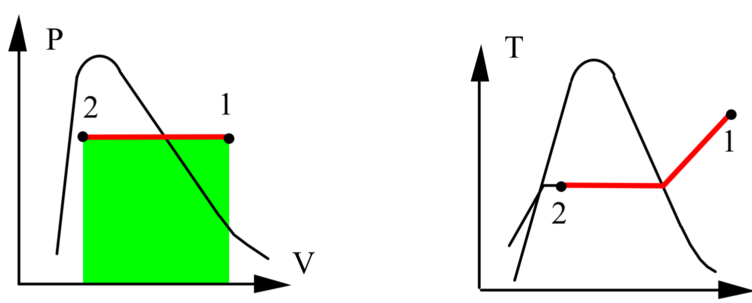
State 2: Table F.7.2 (P, $v_2 = v_1/10 = 0.113$ ft^3/lbm) two-phase state

$x_2 = (v_2 - v_f)/v_{fg} = (0.113 - 0.02087)/0.5488 = 0.1679$

$h_2 = h_f + x_2 h_{fg} = 509.63 + x_2\ 689.62 = 625.42$ Btu/lbm

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1)$

$= 2\ (625.42 - 1567.81) =$ **-1884.8 Btu**



5.155E A piston/cylinder arrangement has the piston loaded with outside atmospheric pressure and the piston mass to a pressure of 20 lbf/in.^{2}, shown in Fig P5.50. It contains water at 25 F, which is then heated until the water becomes saturated vapor. Find the final temperature and specific work and heat transfer for the process.

Solution:

C.V. Water in the piston cylinder.

Continuity: $m_2 = m_1$, Energy: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Process: P = const. = P_1, => $_1w_2 = \int_1^2 P\, dv = P_1(v_2 - v_1)$

State 1: T_1 , P_1 => Table F.7.4 compressed solid, take as saturated solid.

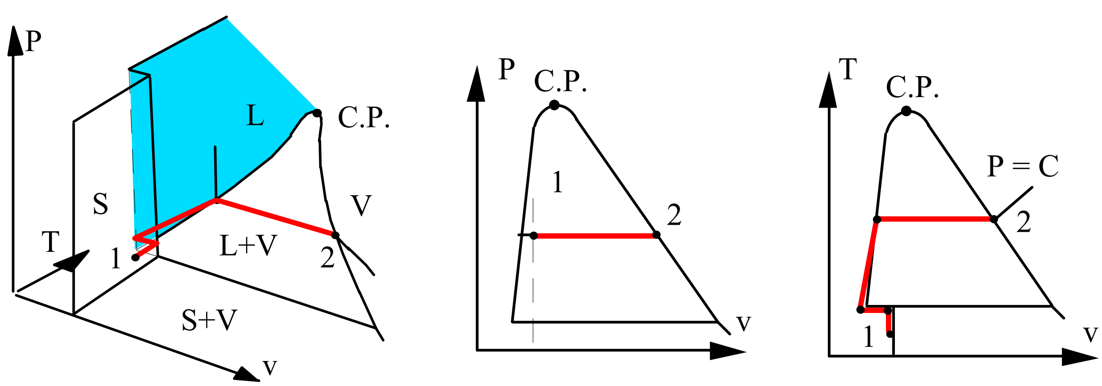
$v_1 = 0.01746$ ft^3/lbm, $u_1 = -146.84$ Btu/lbm

State 2: x = 1, $P_2 = P_1 = 20$ psia due to process => Table F.7.1

$v_2 = v_g(P_2) = 20.09$ ft^3/lbm, T_2 = **228 F** ; $u_2 = 1082$ Btu/lbm

$_1w_2 = P_1(v_2 - v_1) = 20(20.09 - 0.01746) \times 144/778 =$ **74.3 Btu/lbm**

$_1q_2 = u_2 - u_1 + {}_1w_2 = 1082 - (-146.84) + 74.3 =$ **1303 Btu/lbm**



5.156E

A water-filled reactor with volume of 50 ft^3 is at 2000 lbf/in.^{2}, 560 F and placed inside a containment room, as shown in Fig. P5.48. The room is well insulated and initially evacuated. Due to a failure, the reactor ruptures and the water fills the containment room. Find the minimum room volume so the final pressure does not exceed 30 lbf/in.^{2}.

C.V.: Containment room and reactor.

Mass: $m_2 = m_1 = V_{reactor}/v_1 = 50/0.02172 = 2295.7$ lbm

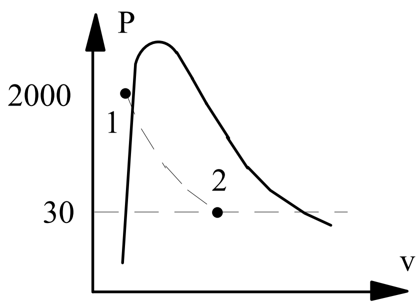
Energy $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = \emptyset \;\Rightarrow\; u_2 = u_1 = 552.5$ Btu/lbm

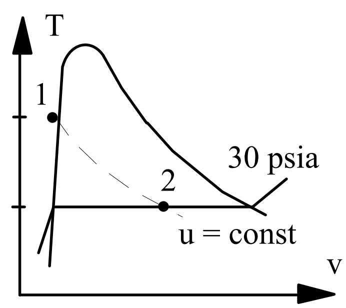
State 2: 30 lbf/in.^{2}, $u_2 < u_g \;\Rightarrow\;$ 2 phase Table F.7.1

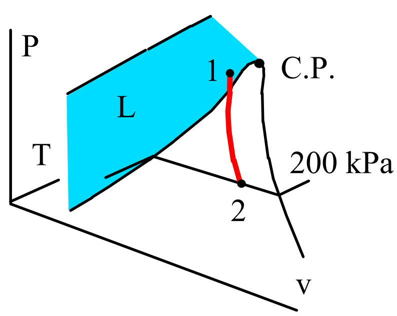
$$u = 552.5 = 218.48 + x_2\, 869.41 \quad\Rightarrow\quad x_2 = 0.3842$$

$$v_2 = 0.017 + 0.3842 \times 13.808 = 5.322 \text{ ft}^3\text{/lbm}$$

$$V_2 = mv_2 = 2295.7 \times 5.322 = \mathbf{12218\ ft^3}$$







5.157E

A piston/cylinder contains 2 lbm of liquid water at 70 F, and 30 lbf/in.^{2}. There is a linear spring mounted on the piston such that when the water is heated the pressure reaches 300 lbf/in.^{2} with a volume of 4 ft^3. Find the final temperature and plot the *P-v* diagram for the process. Calculate the work and the heat transfer for the process.

Solution:

Take CV as the water.

$$m_2 = m_1 = m \;; \qquad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$

State 1: Compressed liquid, take saturated liquid at same temperature.

$$v_1 = v_f(20) = 0.01605 \text{ ft}^3/\text{lbm}, \qquad u_1 = u_f = 38.09 \text{ Btu/lbm}$$

State 2: $v_2 = V_2/m = 4/2 = 2$ ft^3/lbm and P = 300 psia

=> Superheated vapor $T_2 = 600$ F ; $u_2 = 1203.2$ Btu/lbm

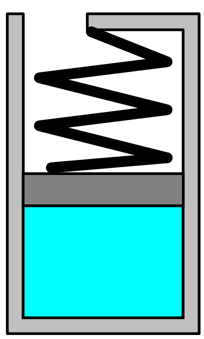
Work is done while piston moves at linearly varying pressure, so we get

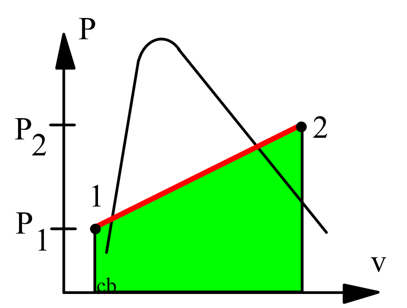
$${}_1W_2 = \int P\, dV = \text{area} = P_{avg}\,(V_2 - V_1)$$

$$= 0.5\times(30+3000)(4 - 0.0321)\ \frac{144}{778} = \mathbf{121.18\ Btu}$$

Heat transfer is found from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 2 \times (1203.2 - 38.09) + 121.18 = \mathbf{2451.4\ Btu}$$





Multistep and Review Problems

5.158E

A twenty pound-mass of water in a piston/cylinder with constant pressure is at 1100 F and a volume of 22.6 ft^3. It is now cooled to 100 F. Show the *P–v* diagram and find the work and heat transfer for the process.

Solution:

C.V. Water

Energy Eq.: $_1Q_2 = m(u_2 - u_1) + {_1W_2} = m(h_2 - h_1)$

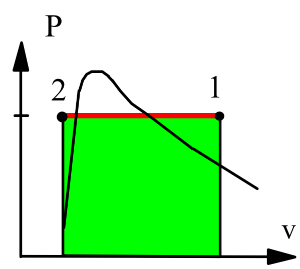
Process Eq.: Constant pressure $\Rightarrow$ $_1W_2 = mP(v_2 - v_1)$

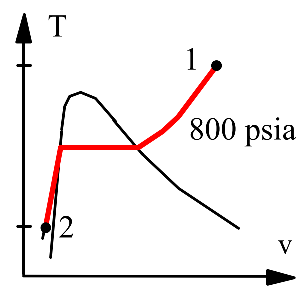
Properties from Table F.7.2 and F.7.3

State 1: T_1, $v_1 = 22.6/20 = 1.13$ ft^3/lbm, $P_1 = 800$ lbf/in^2 , $h_1 = 1567.8$

State 2: 800 lbf/in^2, 100 F

$\Rightarrow$ $v_2 = 0.016092$ ft^3/lbm, $h_2 = 70.15$ Btu/lbm





$_1W_2 = 20 \times 800 \times (0.016092 - 1.13) \times 144/778 =$ **-3299 Btu**

$_1Q_2 = 20 \times (70.15 - 1567.8) =$ **-29 953 Btu**

5.159E

A vertical cylinder fitted with a piston contains 10 lbm of R-22 at 50 F, shown in Fig. P5.64. Heat is transferred to the system causing the piston to rise until it reaches a set of stops at which point the volume has doubled. Additional heat is transferred until the temperature inside reaches 120 F, at which point the pressure inside the cylinder is 200 lbf/in.^{2}.

a. What is the quality at the initial state?

b. Calculate the heat transfer for the overall process.

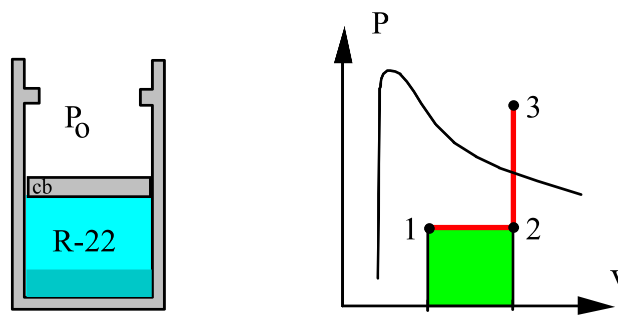
Solution:

C.V. R-22. Control mass goes through process: 1 -> 2 -> 3

As piston floats pressure is constant (1 -> 2) and the volume is constant for the second part (2 -> 3). So we have: $v_3 = v_2 = 2 \times v_1$

State 3: Table F.9.2 (P,T) $v_3 = 0.2959$ ft^3/kg,

$$u_3 = h - Pv = 117.0 - 200 \times 0.2959 \times 144/778 = 106.1 \text{ Btu/lbm}$$



So we can determine state 1 and 2 Table F.9.1:

$$v_1 = 0.14795 = 0.01282 + x_1(0.5432) \quad \Rightarrow \quad x_1 = \mathbf{0.249}$$

$$u_1 = 24.04 + 0.249 \times 74.75 = 42.6 \text{ Btu/lbm}$$

State 2: $v_2 = 0.2959$ ft^3/lbm, $P_2 = P_1 = 98.7$ psia, this is still 2-phase.

$${}_1W_3 = {}_1W_2 = \int_1^2 P dV = P_1(V_2 - V_1)$$

$$= 98.7 \times 10(0.295948 - 0.147974) \times 144/778 = 27.0 \text{ Btu}$$

$${}_1Q_3 = m(u_3 - u_1) + {}_1W_3 = 10(106.1 - 42.6) + 27.0 = \mathbf{662\ Btu}$$

5.160E

A piston/cylinder contains 2 lbm of water at 70 F with a volume of 0.1 ft^3, shown in Fig. P5.129. Initially the piston rests on some stops with the top surface open to the atmosphere, *P*o, so a pressure of 40 lbf/in.^{2} is required to lift it. To what temperature should the water be heated to lift the piston? If it is heated to saturated vapor find the final temperature, volume, and the heat transfer.

Solution:

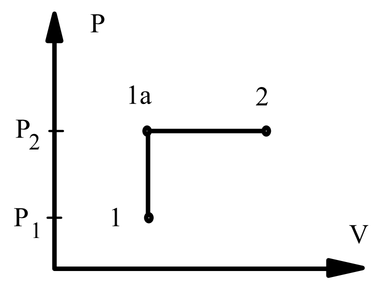
C.V. Water. This is a control mass.

$$m_2 = m_1 = m \;; \quad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$

State 1: 20 C, $v_1 = V/m = 0.1/2 = 0.05$ ft^3/lbm

$x = (0.05 - 0.01605)/867.579 = 0.0003913$

$u_1 = 38.09 + 0.0003913 \times 995.64 = 38.13$ Btu/lbm



To find state 2 check on state 1a:

P = 40 psia, $v = v_1 = 0.05$ ft^3/lbm

Table F.7.1: $v_f < v < v_g = 10.501$

State 2 is saturated vapor at 40 psia as state 1a is two-phase. $T_2 = 267.3$ F

$v_2 = vg = 10.501$ ft^3/lbm , $V_2 = m\, v_2 = 21.0$ ft^3, $u_2 = ug = 1092.27$ Btu/lbm

Pressure is constant as volume increase beyond initial volume.

$${}_1W_2 = \int P\, dV = P_{lift}\,(V_2 - V_1) = 40\,(21.0 - 0.1) \times 144 / 778 = 154.75 \text{ Btu}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 2\,(1092.27 - 38.13) + 154.75 = 2263 \text{ Btu}$$

5.161E

Two tanks are connected by a valve and line as shown in Fig. P5.62. The volumes are both 35 ft^3 with R-134a at 70 F, quality 25% in A and tank B is evacuated. The valve is opened and saturated vapor flows from A into B until the pressures become equal. The process occurs slowly enough that all temperatures stay at 70 F during the process. Find the total heat transfer to the R-134a during the process.

C.V.: A + B

State 1A: Table F.10.1, $u_{A1} = 98.27 + 0.25 \times 69.31 = 115.6$ Btu/lbm

$$v_{A1} = 0.01313 + 0.25 \times 0.5451 = 0.1494 \text{ ft}^3/\text{lbm}$$

$$\Rightarrow \quad m_{A1} = V_A/v_{A1} = 234.3 \text{ lbm}$$

Process: Constant T and total volume. $m_2 = m_{A1}$; $V_2 = V_A + V_B = 70$ ft^3

State 2: T_2 , $v_2 = V_2/m_2 = 70/234.3 = 0.2988$ ft^3/lbm =>

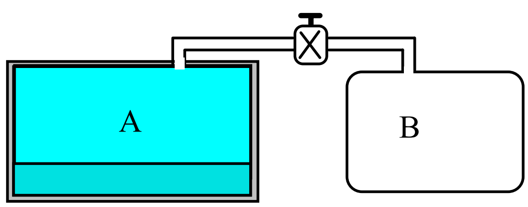
$$x_2 = (0.2988 - 0.01313)/0.5451 = 0.524 ;$$

$$u_2 = 98.27 + 0.524*69.31 = 134.6 \text{ Btu/lbm}$$

The energy equation gives the heat transfer

$$_1Q_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {}_1W_2 = m_2(u_2 - u_{A1})$$

$$= 234.3 \times (134.6 - 115.6) = \mathbf{4452\ Btu}$$



5.162E

Ammonia, NH_3, is contained in a sealed rigid tank at 30 F, $x = 50\%$ and is then heated to 200 F. Find the final state P_2, u_2 and the specific work and heat transfer.

Solution:

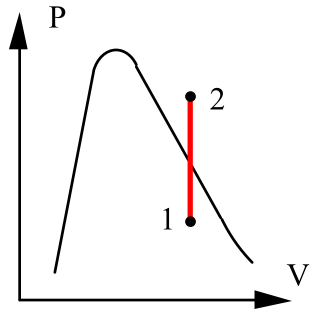
Continuity Eq.: $m_2 = m_1$;

Energy Eq.5.11: $E_2 - E_1 = {}_1Q_2$; $({}_1W_2 = \emptyset)$

Process: $V_2 = V_1 \Rightarrow v_2 = v_1 = 0.02502 + 0.5 \times 4.7945 = 2.422$ ft^3/lbm

State 1: Table F.8.1, $u_1 = 75.06 + 0.5 \times 491.17 = 320.65$ Btu/lbm

Table F.8.2: v_2 & $T_2 \Rightarrow$ between 150 psia and 175 psia



$P_2 = 163$ lbf/in^2, $h_2 = 706.6$ Btu/lbm

linear interpolation

$u_2 = h_2 - P_2v_2 = 706.6 - 163 \times 2.422 \times 144/778$

$= 633.5$ Btu/lbm

Process equation gives no displacement: ${}_1w_2 = \mathbf{0}$;

The energy equation then gives the heat transfer as

$${}_1q_2 = u_2 - u_1 = 633.5 - 320.65 = \mathbf{312.85\ Btu/lbm}$$

5.163E

Water at 70 F, 15 lbf/in.^{2}, is brought to 30 lbf/in.^{2}, 2700 F. Find the change in the specific internal energy, using the water table and the ideal gas water table in combination.

State 1: Table F.7.1 $u_1 \cong u_f = 38.09$ Btu/lbm

State 2: Highest T in Table F.7.2 is 1400 F

Using a Δu from the ideal gas table F.6, we get

$\bar{h}_{2700} - \bar{h}_{2000} = 26002 - 11769 = 14233$ Btu/lbmol= 790 Btu/lbm

$$u_{2700} - u_{1400} = \Delta h - R(2700 - 1400) = 790 - 53.34 \times \frac{1300}{778} = 700.9$$

Since ideal gas change is at low P we use 1400 F, lowest P available 1 lbf/in^2 from steam tables, F.7.2, $u_x = 1543.1$ Btu/lbm as the reference.

$$u_2 - u_1 = (u_2 - u_x)_{ID.G.} + (u_x - u_1)$$
$$= 700.9 + 1543.1 - 38.09 = \mathbf{2206\ Btu/lbm}$$

Solids and Liquids

5.164E

A car with mass 3250 lbm drives with 60 mi/h when the brakes are applied to quickly decrease its speed to 20 mi/h. Assume the brake pads are 1 lbm mass with heat capacity of 0.2 Btu/lbm R and the brake discs/drums are 8 lbm steel where both masses are heated uniformly. Find the temperature increase in the brake assembly.

C.V. Car. Car looses kinetic energy and brake system gains internal u.

No heat transfer (short time) and no work term.

$$m = \text{constant}; \qquad E_2 - E_1 = 0 - 0 = m_{car}\,\tfrac{1}{2}(V_2^2 - V_1^2) + m_{brake}(u_2 - u_1)$$

The brake system mass is two different kinds so split it, also use C_v since we do not have a u table for steel or brake pad material.

$$m_{steel}\, C_v\, \Delta T + m_{pad}\, C_v\, \Delta T = m_{car}\,\tfrac{1}{2}(V_2^2 - V_1^2)$$

$$(8\times0.11 + 1\times0.2)\ \Delta T = 3250 \times0.5\times3200\times1.46667^2 /(32.174\times778) = 446.9 \text{ Btu}$$

$$\Rightarrow \qquad \Delta T = \mathbf{414\ F}$$

5.165E

A 2 lbm steel pot contains 2 lbm liquid water at 60 F. It is now put on the stove where it is heated to the boiling point of the water. Neglect any air being heated and find the total amount of energy needed.

Solution:

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

The steel does not change volume and the change for the liquid is minimal, so ${}_1W_2 \cong 0$.

State 2: $T_2 = T_{sat}\,(1\text{atm}) = 212$ F

Tbl F.7.1 : $u_1 = 28.1$ Btu/lbm, $u_2 = 180.1$ Btu/lbm

Tbl F.2 : $C_{st} = 0.11$ Btu/lbm R

Solve for the heat transfer from the energy equation

$${}_1Q_2 = U_2 - U_1 = m_{st}\,(u_2 - u_1)_{st} + m_{H2O}\,(u_2 - u_1)_{H2O}$$
$$= m_{st}C_{st}\,\,(T_2 - T_1) + m_{H2O}\,(u_2 - u_1)_{H2O}$$

$${}_1Q_2 = 2\text{ lbm} \times 0.11\,\frac{\text{Btu}}{\text{lbm R}} \times (212 - 60)\text{ R} + 2\text{ lbm} \times (180.1 - 28.1)\,\frac{\text{Btu}}{\text{lbm}}$$
$$= 33.4 + 304 = \mathbf{337.4\ Btu}$$

5.166E

A copper block of volume 60 in.^{3} is heat treated at 900 F and now cooled in a 3-ft^3 oil bath initially at 70 F. Assuming no heat transfer with the surroundings, what is the final temperature?

C.V. Copper block and the oil bath.

$$m_{met}(u_2 - u_1)_{met} + m_{oil}(u_2 - u_1)_{oil} = {}_1Q_2 - {}_1W_2 = \emptyset$$

solid and liquid $\quad \Delta u \cong C_V \Delta T$

$$m_{met}C_{Vmet}(T_2 - T_{1,met}) + m_{oil}C_{Voil}(T_2 - T_{1,oil}) = \emptyset$$

$$m_{met} = V\rho = 60 \times 12^{-3} \times 555 = 19.271 \text{ lbm}$$

$$m_{oil} = V\rho = 3.5 \times 57 = 199.5 \text{ lbm}$$

Energy equation becomes

$$19.271 \times 0.092(T_2 - 900) + 199.5 \times 0.43(T_2 - 70) = \emptyset$$

$$\Rightarrow \; T_2 = \mathbf{86.8\ F}$$

5.167E

An engine consists of a 200 lbm cast iron block with a 40 lbm aluminum head, 40 lbm steel parts, 10 lbm engine oil and 12 lbm glycerine (antifreeze). Everything begins at 40 F and as the engine starts, it absorbs a net of 7000 Btu before it reaches a steady uniform temperature. We want to know how hot it becomes.

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

Process: The steel does not change volume and the change for the liquid is minimal, so ${}_1W_2 \cong 0$.

So sum over the various parts of the left hand side in the energy equation

$$m_{Fe}(u_2 - u_1) + m_{Al}(u_2 - u_1)_{Al} + m_{st}(u - u_1)_{st} + m_{oil}(u_2 - u_1)_{oil} + m_{gly}(u_2 - u_1)_{gly} = {}_1Q_2$$

Tbl F.2 : $C_{Fe} = 0.1$, $C_{Al} = 0.215$, $C_{st} = 0.11$ all units of Btu/lbm R

Tbl F.3 : $C_{oil} = 0.46$, $C_{gly} = 0.58$ all units of Btu/lbm R

So now we factor out $T_2 - T_1$ as $u_2 - u_1 = C(T_2 - T_1)$ for each term

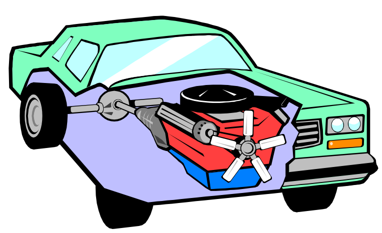
$$[\, m_{Fe}C_{Fe} + m_{Al}C_{Al} + m_{st}C_{st} + m_{oil}C_{oil} + m_{gly}C_{gly} \,]\,(T_2 - T_1) = {}_1Q_2$$

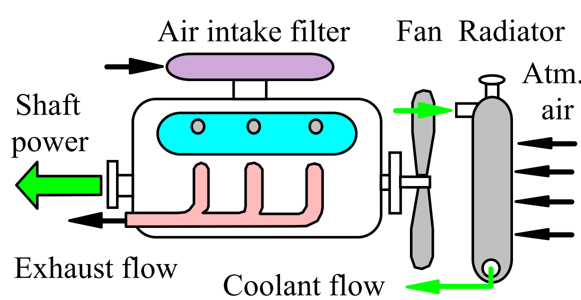
$$T_2 - T_1 = {}_1Q_2 / \Sigma m_i C_i$$

$$= \frac{7000}{200\times 0.1 + 40\times 0.215 + 40\times 0.11 + 10\times 0.46 + 12\times 0.58}$$

$$= \frac{7000}{44.56} = 157 \text{ R}$$

$T_2 = T_1 + 157 = 40 + 157 =$ **197 F**





Ideal Gas

5.168E

A cylinder with a piston restrained by a linear spring contains 4 lbm of carbon dioxide at 70 lbf/in.^{2}, 750 F. It is cooled to 75 F, at which point the pressure is 45 lbf/in.^{2}. Calculate the heat transfer for the process.

Solution:

C.V. The carbon dioxide, which is a control mass.

Continuity Eq.: $m_2 - m_1 = 0$

Energy Eq.: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process Eq.: $P = A + BV$ (linear spring) ${}_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$

Equation of state: $PV = mRT$ (ideal gas)

State 1: $V_1 = mRT_1/P_1 = \frac{4 \times 35.1 \times (750 + 460)}{70 \times 144} = 16.85 \text{ ft}^3$

State 2: $V_2 = mRT_2/P_2 = \frac{4 \times 35.1 \times (75 + 460)}{45 \times 144} = 11.59 \text{ ft}^3$

$${}_1W_2 = \frac{1}{2}(70 + 45)(11.59 - 16.85) \times 144/778 = -55.98 \text{ Btu}$$

To evaluate $u_2 - u_1$ we will use the specific heat at the average temperature.

From Table F.6:

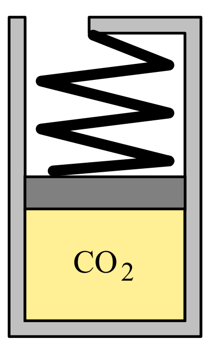
$$C_{po}(T_{avg}) = \frac{\Delta h}{\Delta T} = \frac{1}{M}\frac{6927\text{-}0}{1200\text{-}537} = \frac{10.45}{44.01} = 0.2347 \text{ Btu/lbm R}$$

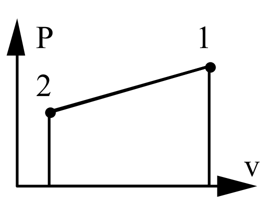
$$\Rightarrow \; C_V = C_p - R = 0.2375 - 35.10/778 = 0.1924 \text{ Btu/lbm R}$$

For comparison the value from Table F.4 at 77 F is $C_{vo} = 0.156$ Btu/lbm R

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_{vo}(T_2 - T_1) + {}_1W_2$$

$$= 4 \times 0.1924(75 - 750) - 55.98 = \mathbf{-575.46\ Btu}$$





5.169E

An insulated cylinder is divided into two parts of 10 ft^3 each by an initially locked piston. Side A has air at 2 atm, 600 R and side B has air at 10 atm, 2000 R as shown in Fig. P5.95. The piston is now unlocked so it is free to move, and it conducts heat so the air comes to a uniform temperature $T_A = T_B$. Find the mass in both A and B and also the final T and P.

C.V. A + B . Then ${}_1Q_2 = \emptyset$, ${}_1W_2 = \emptyset$.

Force balance on piston: $P_A A = P_B A$, so final state in A and B is the same.

State 1A: $u_{A1} = 102.457$; $m_A = \frac{PV}{RT} = \frac{29.4 \times 10 \times 144}{53.34 \times 600} = \mathbf{1.323\ lbm}$

State 1B: $u_{B1} = 367.642$; $m_B = \frac{PV}{RT} = \frac{147 \times 10 \times 144}{53.34 \times 2000} = \mathbf{1.984\ lbm}$

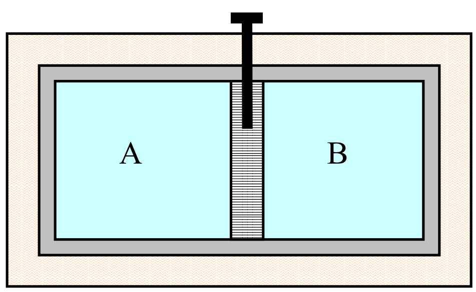
$m_A(u_2 - u_1)_A + m_B(u_2 - u_1)_B = \emptyset$

$(m_A + m_B)u_2 = m_A u_{A1} + m_B u_{B1}$

$= 1.323 \times 102.457 + 1.984 \times 367.642 = 864.95$ Btu

$u_2 = 864.95/3.307 = 261.55 \quad \Rightarrow \quad T_2 = \mathbf{1475\ R}$

$P = m_{tot}RT_2/V_{tot} = \frac{3.307 \times 53.34 \times 1475}{20 \times 144} = \mathbf{90.34\ lbf/in^2}$



5.170E

A 65 gallons rigid tank contains methane gas at 900 R, 200 psia. It is now cooled down to 540 R. Assume ideal gas and find the needed heat transfer.

Solution:

Ideal gas and recall from Table A.1 that 1 gal = 231 in^3,

$$m = P_1V/RT_1 = \frac{200 \times 65 \times 231}{96.35 \times 900 \times 12} = 2.886 \text{ lbm}$$

Process: $V = \text{constant} = V_1 \quad => \quad {}_1W_2 = 0$

Use specific heat from Table F.4

$$u_2 - u_1 = C_v (T_2 - T_1) = 0.415 (900 - 540) = -149.4 \text{ Btu/lbm}$$

Energy Equation

$${}_1Q_2 = m(u_2 - u_1) = 2.886 (-149.4) = \mathbf{-431.2 \text{ Btu}}$$

5.171E

Air in a piston/cylinder at 30 lbf/in.^{2}, 1080 R, is shown in Fig. P5.69. It is expanded in a constant-pressure process to twice the initial volume (state 2). The piston is then locked with a pin, and heat is transferred to a final temperature of 1080 R. Find *P*, *T*, and *h* for states 2 and 3, and find the work and heat transfer in both processes.

C.V. Air. Control mass $m_2 = m_3 = m_1$

$1 \rightarrow 2$: $u_2 - u_1 = {}_1q_2 - {}_1w_2$; ${}_1w_2 = \int P dv = P_1(v_2 - v_1) = R(T_2 - T_1)$

Ideal gas $Pv = RT \Rightarrow T_2 = T_1 v_2/v_1 = 2T_1 = \mathbf{2160\ R}$

$P_2 = P_1 = 30\ \text{lbf/in}^2$, $h_2 = 549.357$ ${}_1w_2 = RT_1 = 74.05$ Btu/lbm

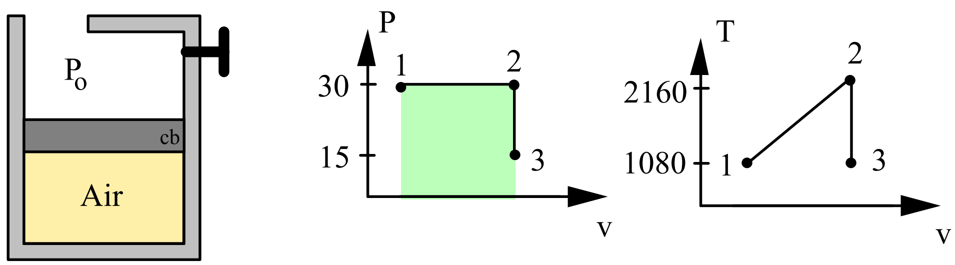
Table F.5 $\mathbf{h_2 = 549.357\ Btu/lbm}$, $\mathbf{h_3 = h_1 = 261.099\ Btu/lbm}$

${}_1q_2 = u_2 - u_1 + {}_1w_2 = h_2 - h_1 = 549.357 - 261.099 = \mathbf{288.26\ Btu/lbm}$

$2 \rightarrow 3$: $v_3 = v_2 = 2v_1 \Rightarrow \mathbf{{}_2w_3 = 0,}$

$P_3 = P_2T_3/T_2 = P_1/2 = \mathbf{15\ lbf/in^2}$

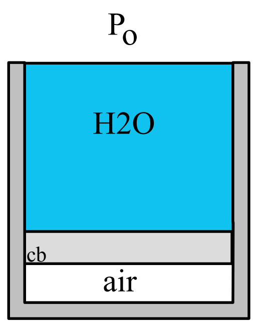
${}_2q_3 = u_3 - u_2 = 187.058 - 401.276 = \mathbf{-214.2\ Btu/lbm}$

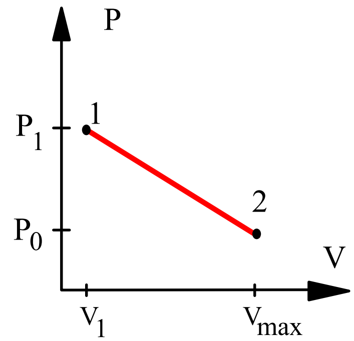


5.172E

A 30-ft high cylinder, cross-sectional area 1 ft^2, has a massless piston at the bottom with water at 70 F on top of it, as shown in Fig. P5.93. Air at 540 R, volume 10 ft^3 under the piston is heated so that the piston moves up, spilling the water out over the side. Find the total heat transfer to the air when all the water has been pushed out.

Solution





The water on top is compressed liquid and has mass

$V_{H2O} = V_{tot} - V_{air} = 30 \times 1 - 10 = 20 \text{ ft}^3$

$m_{H2O} = V_{H2O}/v_f = 20/0.016051 = 1246 \text{ lbm}$

Initial air pressure is: $P_1 = P_0 + m_{H2O}g/A = 14.7 + \frac{g}{1 \times 144} = 23.353 \text{ psia}$

and then $m_{air} = \frac{PV}{RT} = \frac{23.353 \times 10 \times 144}{53.34 \times 540} = 1.1675 \text{ lbm}$

State 2: $P_2 = P_0 = 14.7 \text{ lbf/in}^2, \quad V_2 = 30 \times 1 = 30 \text{ ft}^3$

$_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$

$= \frac{1}{2}(23.353 + 14.7)(30 - 10) \times 144 / 778 = 70.43 \text{ Btu}$

State 2: $P_2, V_2 \Rightarrow T_2 = \frac{T_1 P_2 V_2}{P_1 V_1} = \frac{540 \times 14.7 \times 30}{23.353 \times 10} = 1019.7 \text{ R}$

$_1Q_2 = m(u_2 - u_1) + {_1W_2} = 1.1675 \times 0.171\ (1019.7 - 540) + 70.43$

$=$ **166.2 Btu**

Polytropic Process

5.173E

An air pistol contains compressed air in a small cylinder, as shown in Fig. P5.112. Assume that the volume is 1 in.^{3}, pressure is 10 atm, and the temperature is 80 F when armed. A bullet, *m* = 0.04 lbm, acts as a piston initially held by a pin (trigger); when released, the air expands in an isothermal process (*T* = constant). If the air pressure is 1 atm in the cylinder as the bullet leaves the gun, find

a. The final volume and the mass of air.

b. The work done by the air and work done on the atmosphere.

c. The work to the bullet and the bullet exit velocity.

C.V. Air. Air ideal gas:

$$m_{air} = P_1V_1/RT_1 = \frac{10 \times 14.7 \times 1}{53.34 \times 539.67 \times 12} = \mathbf{4.26{\times}10^{-5}\ lbm}$$

Process: $PV = \text{const} = P_1V_1 = P_2V_2 \Rightarrow V_2 = V_1P_1/P_2 = \mathbf{10\ in^3}$

$${}_1W_2 = \int PdV = P_1V_1 \int (1/V)\, dV = P_1V_1 \ln(V_2/V_1) = \mathbf{0.0362\ Btu}$$

$${}_1W_{2,ATM} = P_0(V_2 - V_1) = \mathbf{0.0142\ Btu}$$

$$W_{bullet} = {}_1W_2 - {}_1W_{2,ATM} = 0.022\ \text{Btu} = \frac{1}{2}\, m_{bullet}(\mathbf{V}_{ex})^2$$

$$\mathbf{V}_{ex} = (2W_{bullet}/m_B)^{1/2} = (2{\times}0.022{\times}778{\times}32.174 / 0.04)^{1/2} = \mathbf{165.9\ ft/s}$$

5.174E

A piston/cylinder in a car contains 12 in.^{3} of air at 13 lbf/in.^{2}, 68 F, shown in Fig. P5.66. The air is compressed in a quasi-equilibrium polytropic process with polytropic exponent n = 1.25 to a final volume six times smaller. Determine the final pressure, temperature, and the heat transfer for the process.

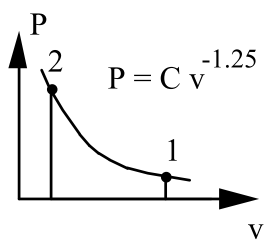
C.V. Air. This is a control mass going through a polytropic process.

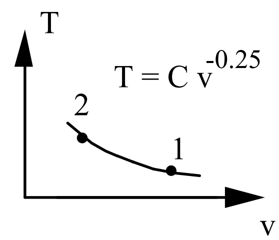
Cont.: $m_2 = m_1$;   Energy: $E_2 - E_1 = m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: Pv^n = const. ;   Ideal gas: $Pv = RT$

$$P_1v_1^n = P_2v_2^n \;\Rightarrow\; P_2 = P_1\left(\frac{v_1}{v_2}\right)^n = 13 \times (6)^{1.25} = \mathbf{122.08\ lbf/in^2}$$

$$T_2 = T_1(P_2v_2/P_1v_1) = 527.67(122.08/13 \times 6) = \mathbf{825.9\ R}$$





$$m = \frac{PV}{RT} = \frac{13 \times 12 \times 12^{-1}}{53.34 \times 527.67} = 4.619{\times}10^{-4} \text{ lbm}$$

$${}_1w_2 = \int Pdv = \frac{1}{1 - n}(P_2v_2 - P_1v_1) = \frac{R}{1 - n}(T_2 - T_1)$$

$$= 53.34\left(\frac{825.9 - 527.67}{(1 - 1.25) \times 778}\right) = -81.79 \text{ Btu/lbm}$$

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 141.64 - 90.05 - 81.79 = -30.2 \text{ Btu/lbm}$$

$${}_1Q_2 = m\ {}_1q_2 = 4.619{\times}10^{-4} \times (-30.2) = \mathbf{-0.0139\ Btu}$$

5.175E

Oxygen at 50 lbf/in.^{2}, 200 F is in a piston/cylinder arrangement with a volume of 4 ft^3. It is now compressed in a polytropic process with exponent, *n* = 1.2, to a final temperature of 400 F. Calculate the heat transfer for the process.

Continuity: $m_2 = m_1$; Energy: $E_2 - E_1 = m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: T, P and ideal gas, small change in T, so use Table C.4

$$\Rightarrow \quad m = \frac{P_1V_1}{RT_1} = \frac{50 \times 4 \times 144}{48.28 \times 659.67} = 0.9043 \text{ lbm}$$

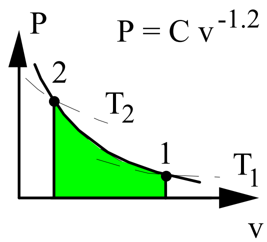
Process: PV^n = constant

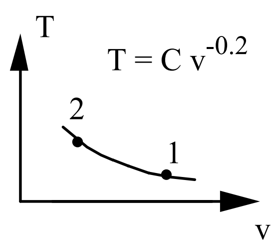
$${}_1W_2 = \frac{1}{1\text{-}n}(P_2V_2 - P_1V_1) = \frac{mR}{1\text{-}n}(T_2 - T_1) = \frac{0.9043 \times 48.28}{1 - 1.2} \times \frac{400 - 200}{778}$$

$$= -\ 56.12 \text{ Btu}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 \cong mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.9043 \times 0.158\,(400 - 200) - 56.12 = \mathbf{-\ 27.54\ Btu}$$





5.176E

Helium gas expands from 20 psia, 600 R and 9 ft^3 to 15 psia in a polytropic process with n = 1.667. How much heat transfer is involved?

Solution:

C.V. Helium gas, this is a control mass.

Energy equation: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process equation: $PV^n = \text{constant} = P_1V_1^n = P_2V_2^n$

Ideal gas (F.4): $m = PV/RT = \frac{20 \times 9 \times 144}{386 \times 600} = 0.112 \text{ lbm}$

Solve for the volume at state 2

$$V_2 = V_1 (P_1/P_2)^{1/n} = 9 \times \left(\frac{20}{15}\right)^{0.6} = 10.696 \text{ ft}^3$$

$$T_2 = T_1 P_2V_2/(P_1V_1) = 600 \frac{15 \times 10.696}{20 \times 9} = 534.8 \text{ R}$$

Work from Eq.4.4

$$_1W_2 = \frac{P_2V_2 - P_1 V_1}{1-n} = \frac{15 \times 10.696 - 20 \times 9}{1 - 1.667} \text{ psia ft}^3 = 29.33 \text{ psia ft}^3$$

$$= 4223 \text{ lbf-ft} = 5.43 \text{ Btu}$$

Use specific heat from Table F.4 to evaluate $u_2 - u_1$, $C_v = 0.744$ Btu/lbm R

$$_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m C_v (T_2 - T_1) + {}_1W_2$$

$$= 0.112 \times 0.744 \times (534.8 - 600) + 5.43 = \mathbf{-0.003 \text{ Btu}}$$

5.177E

A cylinder fitted with a frictionless piston contains R-134a at 100 F, 80% quality, at which point the volume is 3 Gal. The external force on the piston is now varied in such a manner that the R-134a slowly expands in a polytropic process to 50 lbf/in.^{2}, 80 F. Calculate the work and the heat transfer for this process.

Solution:

C.V. The mass of R-134a. Properties in Table F.10.1

$$v_1 = v_f + x_1\, v_{fg} = 0.01387 + 0.8 \times 0.3278 = 0.2761 \text{ ft}^3/\text{lbm}$$

$$u_1 = 108.51 + 0.8 \times 62.77 = 158.73 \text{ Btu/lbm}; \quad P_1 = 138.926 \text{ psia}$$

$$m = V/v_1 = 3 \times 231 \times 12^{-3} / 0.2761 = 0.401/ 0.2761 = 1.4525 \text{ lbm}$$

State 2: $v_2 = 1.0563 \text{ ft}^3/\text{lbm}$ (sup.vap.);

$$u_2 = 181.1 - 50 \times 1.0563 \times 144/778 = 171.32 \text{ Btu/lbm}$$

Process: $n = \ln \frac{P_1}{P_2} / \ln \frac{V_2}{V_1} = \ln \frac{138.926}{50} / \ln \frac{1.0563}{9.2761} = 0.7616$

$$_1W_2 = \int P\, dV = \frac{P_2 V_2 - P_1 V_1}{1 - n}$$

$$= \frac{50 \times 1.0563 - 138.926 \times 0.2761}{1 - 0.7616} \times 1.4525 \times \frac{144}{778} = \mathbf{16.3\ Btu}$$

$$_1Q_2 = m(u_2 - u_1) + {_1W_2} = 1.4525\,(171.32 - 158.73) + 16.3 = \mathbf{34.6\ Btu}$$

5.178E

A piston cylinder contains argon at 20 lbf/in.^{2}, 60 F, and the volume is 4 ft^3. The gas is compressed in a polytropic process to 100 lbf/in.^{2}, 550 F. Calculate the heat transfer during the process.

Find the final volume, then knowing P_1, V_1, P_2, V_2 the polytropic exponent can be determined. Argon is an ideal monatomic gas (Cv is constant).

$$V_2 = V_1 = (P_1/P_2)/(T_2/T_1) = 4 \times \frac{20}{100} \times \frac{1009.67}{519.67} = 1.554 \text{ ft}^3$$

Process: $PV^n = \text{const.} \Rightarrow n = \ln \frac{P_1}{P_2} / \ln \frac{V_2}{V_1} = \ln \frac{100}{20} / \ln \frac{4}{1.554} = 1.702$

$$_1W_2 = \frac{1}{1\text{-}n}(P_2V_2 - P_1V_1) = \frac{100\times1.554 - 20\times4}{1\text{-}1.702} \times \frac{144}{778} = -19.9 \text{ Btu}$$

$$m = PV/RT = 20 \times 4 \times 144 / (38.68 \times 519.67) = 0.5731 \text{ lbm}$$

$$_1Q_2 = m(u_2 - u_1) + {_1W_2} = m\, Cv\, (T_2 - T_1) + {_1W_2}$$

$$= 0.5731 \times 0.0745 \times (550 - 60) - 19.9 = \mathbf{1.0\ Btu}$$

Rates of Energy

5.179E

A small elevator is being designed for a construction site. It is expected to carry four 150 lbm workers to the top of a 300-ft-tall building in less than 2 min. The elevator cage will have a counterweight to balance its mass. What is the smallest size (power) electric motor that can drive this unit?

$$m = 4\times150 = 600 \text{ lbm} ; \qquad \Delta Z = 300 \text{ ft} ; \qquad \Delta t = 2 \text{ minutes}$$

$$-\dot{W} = \Delta\dot{PE} = m \frac{g\Delta Z}{\Delta t} = \frac{600 \times 32.174 \times 300}{32.174 \times 2 \times 60} \frac{1}{550} = \mathbf{2.73\ hp}$$

5.180E

Water is in a piston cylinder maintaining constant P at 330 F, quality 90% with a volume of 4 ft^3. A heater is turned on heating the water with 10 000 Btu/h. What is the elapsed time to vaporize all the liquid?

Solution:

Control volume water.

Continuity Eq.: $m_{tot} = \text{constant} = m_{vapor} + m_{liq}$

on a rate form: $\dot{m}_{tot} = 0 = \dot{m}_{vapor} + \dot{m}_{liq} \quad \Rightarrow \quad \dot{m}_{liq} = -\dot{m}_{vapor}$

Energy equation: $\dot{U} = \dot{Q} - \dot{W} = \dot{m}_{vapor}\, u_{fg} = \dot{Q} - P\, \dot{m}_{vapor}\, v_{fg}$

Rearrange to solve for $\dot{m}_{vapor}$

$$\dot{m}_{vapor}\,(u_{fg} + Pv_{fg}) = \dot{m}_{vapor}\, h_{fg} = \dot{Q}$$

From table F.7.1

$h_{fg} = 887.5$ Bt/lbm, $v_1 = 0.01776 + 0.9\ 4.2938 = 3.8822\ ft^3/lbm$

$m_1 = V_1/v_1 = 4/3.8822 = 1.0303$ lbm, $m_{liq} = (1-x_1)m_1 = 0.10303$ lbm

$$\dot{m}_{vapor} = \dot{Q}/h_{fg} = \frac{10\ 000}{887.5}\ \frac{\text{Btu/h}}{\text{Btu/lbm}} = 11.2676 \text{ lbm/h} = 0.00313 \text{ lbm/s}$$

$\Delta t = m_{liq} / \dot{m}_{vapor} = 0.10303 / 0.00313 =$ **32.9 s**

5.181E

A computer in a closed room of volume 5000 ft^3 dissipates energy at a rate of 10 hp. The room has 100 lbm of wood, 50 lbm of steel and air, with all material at 540 R, 1 atm. Assuming all the mass heats up uniformly how long time will it take to increase the temperature 20 F?

C.V. Air, wood and steel. $m_2 = m_1$; $U_2 - U_1 = {}_1Q_2 = \dot{Q}\,\Delta t$

The total volume is nearly all air, but we can find volume of the solids.

$V_{wood} = m/\rho = 100/44.9 = 2.23\ ft^3$; $V_{steel} = 50/488 = 0.102\ ft^3$

$V_{air} = 5000 - 2.23 - 0.102 = 4997.7\ ft^3$

$$m_{air} = PV/RT = 14.7 \times 4997.7 \times 144/(53.34 \times 540) = 367.3\ \text{lbm}$$

We do not have a u table for steel or wood so use heat capacity.

$$\Delta U = [m_{air}\,C_v + m_{wood}\,C_v + m_{steel}\,C_v]\,\Delta T$$
$$= (367.3 \times 0.171 + 100 \times 0.3 + 50 \times 0.11)\ 20$$
$$= 1256.2 + 600 + 110 = 1966\ \text{Btu} = \dot{Q} \times \Delta t = 10 \times (550/778) \times \Delta t$$

$$\Rightarrow \quad \Delta t = [1966/10]\,\frac{778}{550} = 278\ \text{sec} = \mathbf{4.6\ minutes}$$

5.182E

A closed cylinder is divided into two rooms by a frictionless piston held in place by a pin, as shown in Fig. P5.138. Room A has 0.3 ft^3 air at 14.7 lbf/in.^{2}, 90 F, and room B has 10 ft^3 saturated water vapor at 90 F. The pin is pulled, releasing the piston and both rooms come to equilibrium at 90 F. Considering a control mass of the air and water, determine the work done by the system and the heat transfer to the cylinder.

Solution:

C.V. A + B, control mass of constant total volume.

Energy equation: $m_A(u_2 - u_1)_A + m_B(u_{B2} - u_{B1}) = {}_1Q_2 - {}_1W_2$

Process equation: $V = C \;\Rightarrow\; {}_1W_2 = 0$

$T = C \;\Rightarrow\; (u_2 - u_1)_A = 0$ (ideal gas)

The pressure on both sides of the piston must be the same at state 2.

Since two-phase: $P_2 = P_{g\ H_2O\ at\ 90\ F} = P_{A2} = P_{B2} = 4.246$ kPa

Air, I.G.: $P_{A1}V_{A1} = m_AR_AT = P_{A2}V_{A2} = P_{g\ H_2O\ at\ 90\ F}\, V_{A2}$

$$\rightarrow V_{A2} = \frac{14.7 \times 0.3}{0.6988} = 6.31 \text{ ft}^3$$

Now the water volume is the rest of the total volume

$V_{B2} = V_{A1} + V_{B1} - V_{A2} = 0.30 + 10 - 6.31 = 3.99 \text{ ft}^3$

$m_B = \frac{V_{B1}}{v_{B1}} = \frac{10}{467.7} = 0.02138 \text{ lbm} \quad \rightarrow \quad v_{B2} = 186.6 \text{ ft}^3\text{/lbm}$

$186.6 = 0.016099 + x_{B2} \times (467.7 - 0.016) \quad => \quad x_{B2} = 0.39895$

$u_{B2} = 58.07 + 0.39895 \times 982.2 = 449.9$ Btu/lbm; $u_{B1} = 1040.2$

${}_1Q_2 = m_B(u_{B2} - u_{B1}) = 0.02138\ (449.9 - 1040.2) =$ **-12.6 Btu**