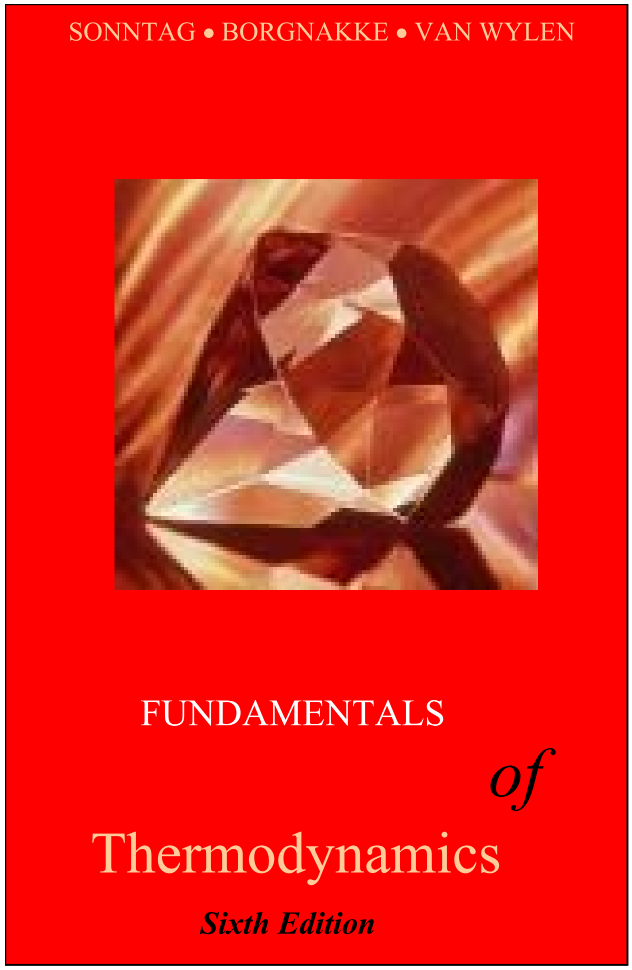
SOLUTION MANUAL
ENGLISH UNIT PROBLEMS
CHAPTER 3



CHAPTER 3

SUBSECTION	**PROB NO.**
Concept-Study Guide Problems	128-132
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Correspondence table

The correspondence between the problem set in this sixth edition versus the problem set in the 5'th edition text. Problems that are new are marked new and the SI number refers to the corresponding SI unit problem.

New	**5th Ed.**	**SI**	**New**	**5th Ed.**	**SI**
128	new	5	143	77E	53
129	new	7	144	new	62
130	new	9	145	79E	58
131	new	11	146	62E	69
132	new	17	147	new	65
133	new	23	148	69E c+d 70E d	-
134	61E	27	149	72E	81
135	68E a-c	30	150	64E	113
136	68E d-f	30	151	new	74
137	new	40	152	81E	49
138	70E	36	153	new	99
139	73E	47	154	71E	95
140	74E	41	155	80E	61
141	new	44	156	83E	106
142	76E	51	157	65E	89
			158	66E	-

Concept Problems

3.128E

Cabbage needs to be cooked (boiled) at 250 F. What pressure should the pressure cooker be set for?

Solution:

If I need liquid water at 250 F I must have a pressure that is at least the saturation pressure for this temperature.

Table F.7.1: 250 F P_{sat} = **29.823 psia.**

3.129E

If I have 1 ft^3 of ammonia at 15 psia, 60 F how much mass is that?

Ammonia Tables F.8:

F.8.1 P_{sat} = 107.64 psia at 60 F so superheated vapor.

F.8.2 v = 21.5641 ft^3/lbm under subheading 15 psia

$$m = \frac{V}{v} = \frac{1 \text{ ft}^3}{21.5641 \text{ ft}^3\text{/lbm}} = \mathbf{0.0464 \ lbm}$$

3.130E

For water at 1 atm with a quality of 10% find the volume fraction of vapor.

This is a two-phase state at a given pressure:

Table F.7.2: v_f = 0.01 672 ft^3/lbm, v_g = 26.8032 ft^3/lbm

From the definition of quality we get the masses from total mass, m, as

$$m_f = (1 - x)\, m, \qquad m_g = x\, m$$

The volumes are

$$V_f = m_f\, v_f = (1 - x)\, m\, v_f, \qquad V_g = m_g\, v_g = x\, m\, v_g$$

So the volume fraction of vapor is

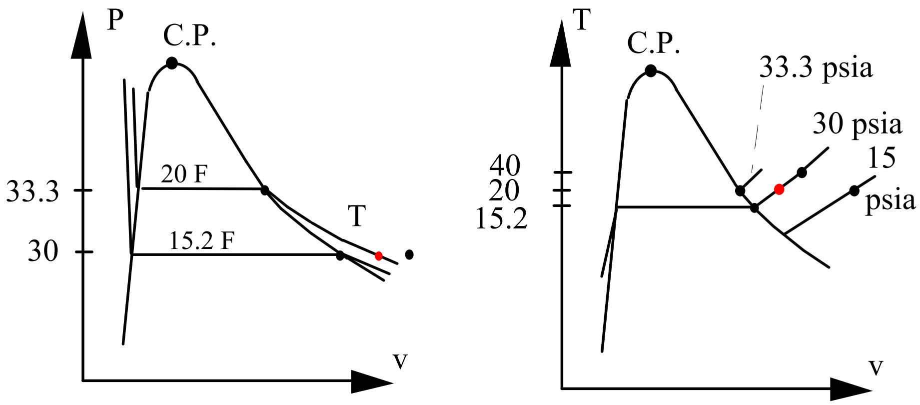
$$\text{Fraction} = \frac{V_g}{V} = \frac{V_g}{V_g + V_f} = \frac{x\, m\, v_g}{x\, m\, v_g + (1 - x) m\, v_f}$$

$$= \frac{0.1 \times 26.8032}{0.1 \times 26.8032 + 0.9 \times 0.016\,72} = \frac{2.68032}{2.69537} = \mathbf{0.9944}$$

Notice that the liquid volume is only about 0.5% of the total. We could also have found the overall $v = v_f + xv_{fg}$ and then V = m v.

3.131E

Locate the state of R-134a at 30 psia, 20 F. Indicate in both the P-v and the T-v diagrams the location of the nearest states listed in the printed table F.10



3.132E

Calculate the ideal gas constant for argon and hydrogen based on Table F.1 and verify the value with Table F.4

The gas constant for a substance can be found from the universal gas constant from table A.1 and the molecular weight from Table F.1

Argon: $$R = \frac{\bar{R}}{M} = \frac{1.98589}{39.948} = \mathbf{0.04971\ \frac{Btu}{lbm\ R} = 38.683\ \frac{lbf\text{-}ft}{lbm\ R}}$$

Hydrogen: $$R = \frac{\bar{R}}{M} = \frac{1.98589}{2.016} = \mathbf{0.98506\ \frac{Btu}{lbm\ R} = 766.5\ \frac{lbf\text{-}ft}{lbm\ R}}$$

Recall from Table A.1: 1 Btu = 778.1693 lbf-ft

Phase Diagrams

3.133E

Water at 80 F can exist in different phases dependent on the pressure. Give the approximate pressure range in lbf/in^2 for water being in each one of the three phases, vapor, liquid or solid.

Solution:

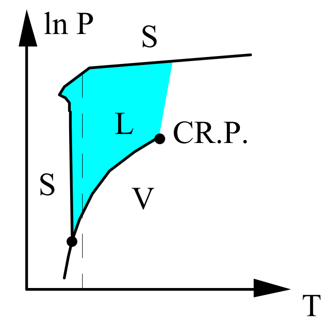
The phases can be seen in Fig. 3.7, a sketch of which is shown to the right.

T = 80 F = 540 R = 300 K

From Fig. 3.7:

$P_{VL} \approx 4 \times 10^{-3}$ MPa = 4 kPa = 0.58 psia,

$P_{LS} = 10^3$ MPa = 145 038 psia



0 < P <	**0.58 psia**	**VAPOR**
0.58 psia < P <	**145 038 psia**	**LIQUID**
P >	**145 038 psia**	**SOLID(ICE)**

3.134E

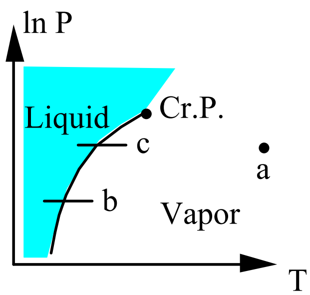
A substance is at 300 lbf/in.^{2}, 65 F in a rigid tank. Using only the critical properties can the phase of the mass be determined if the substance is nitrogen, water or propane?

Solution: Find state relative to the critical point properties, Table F.1

a)	Nitrogen	492 lbf/in.^{2}	227.2 R
b)	Water	3208 lbf/in.^{2}	1165.1 R
c)	Propane	616 lbf/in.^{2}	665.6 R

$P < P_c$ for all and $T = 65$ F $= 65 + 459.67 = 525$ R

a)	N_2	$T >> T_c$	Yes gas and $P < P_c$
b)	H_2O	$T << T_c$	$P << P_c$ so you cannot say
c)	C_3H_8	$T < T_c$	$P < P_c$ you cannot say



General Tables

3.135E

Determine whether water at each of the following states is a compressed liquid, a superheated vapor, or a mixture of saturated liquid and vapor.

Solution: All cases can be seen from Table F.7.1

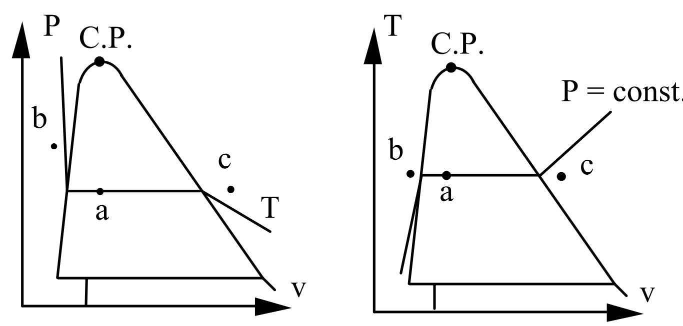
a. 1800 lbf/in.^{2}, 0.03 ft^3/lbm

v_g = **0.2183,** v_f = **0.02472** ft^3/lbm, so **liquid + vapor mixture**

b. 150 lbf/in.^{2}, 320 F: **compressed liquid** $P > P_{sat}(T)$ = **89.6 lbf/in^2**

c. 380 F, 3 ft^3/lbm: **sup. vapor** $v > v_g(T)$ = **2.339** ft^3/lbm

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



3.136E

Determine whether water at each of the following states is a compressed liquid, a superheated vapor, or a mixture of saturated liquid and vapor.

Solution: All cases can be seen from Table F.7.1

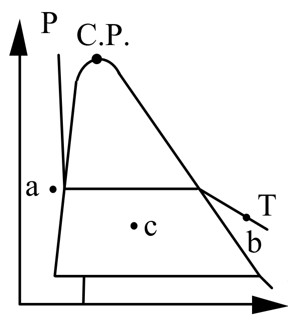
a. 2 lbf/in.^{2}, 50 F: **compressed liquid** $P > P_{sat}(T) = \mathbf{0.178}$

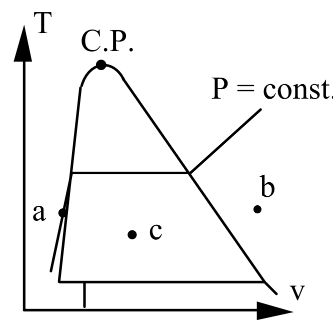
b. 270 F, 30 lbf/in.^{2}: **sup. vapor** $P < P_{sat}(T) = \mathbf{41.85\ lbf/in^2}$

c. 160 F, 10 ft^3/lbm

$v_g = \mathbf{77.22}$, $v_f = \mathbf{0.0164}$ ft^3/lbm, so **liquid + vapor mixture**

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





3.137E

Give the phase and the missing property of P, T, v and x.

a. R-134a $T = -10$ F, $P = 18$ psia

b. R-134a $P = 50$ psia, $v = 1.3$ ft^3/lbm

c. NH_3 $T = 120$ F, $v = 0.9$ ft^3/lbm

d. NH_3 $T = 200$ F, $v = 11$ ft^3/lbm

Solution:

a. Look in Table F.10.1 at –10 F: $P > P_{sat} = 16.76$ psia

This state is compressed liquid so x is undefined and

$$v = v_f = 0.01173 \text{ ft}^3\text{/lbm}$$

b. Look in Table F.10.1 close to 50 psia there we see

$$v > v_g = 0.95 \text{ ft}^3\text{/lbm} \quad \text{so} \quad \textbf{superheated vapor}$$

Look then in Table F.10.2 under 50 psia which is not printed so we must interpolate between the 40 and 60 psia sections.

(60 psia, 1.3 ft^3/lbm) : T = 300 F

(40 psia, 1.3 ft^3/lbm) : T = 66.6 F

Linear interpolation between these gives T = 183 F for a better accuracy we must use the computer software.

c. Look in Table F.8.1 at 120 F: $v < v_g = 1.0456$ ft^3/lbm so **two-phase**

$$P = P_{sat} = \mathbf{286.5\ psia}$$

$$x = \frac{v - v_f}{v_{fg}} = \frac{0.9 - 0.02836}{1.0172} = \mathbf{0.8569}$$

d. Look in Table F.8.1 at 200 F: $v > v_g = 0.3388$ ft^3/lbm so **sup. vapor**

Look in Table F.8.2 start anywhere say at

15 psia, 200 F there we see v = 27.6 ft^3/lbm so P larger

We can bracket the state between 35 and 40 psia so we get

$$P = 35 + 5\,\frac{11 - 11.74}{10.2562 - 11.74} = \mathbf{37.494\ psia}$$

3.138E

Give the phase and the specific volume.

Solution:

a. R-22 $T = -10$ F, $P = 30$ lbf/in.^{2} Table C.10.1 $P < P_{sat} = 31.2$ psia

$\Rightarrow$ sup.vap. $v \cong 1.7439 + \frac{-10+11.71}{11.71}(1.7997 - 1.7439) = \mathbf{1.752\ ft^3/lbm}$

b. R-22 $T = -10$ F, $P = 40$ lbf/in.^{2} Table C.10.1 $P_{sat} = 31.2$ psia

$P > P_{sat} \Rightarrow$ compresssed Liquid $v \cong v_f = \mathbf{0.01178\ ft^3/lbm}$

c. H_2O $T = 280$ F, $P = 35$ lbf/in.^{2} Table C.8.1 $P < P_{sat} = 49.2$ psia

$\Rightarrow$ sup.vap $v \cong 21.734 + (10.711 - 21.734) \times (15/20) = \mathbf{1.0669\ ft^3/lbm}$

d. NH_3 $T = 60$ F, $P = 15$ lbf/in.^{2} Table C.9.1 $P_{sat} = 107.6$ psia

$P < P_{sat} \Rightarrow$ sup.vap $v \cong \mathbf{21.564\ ft^3/lbm}$

3.139E

A water storage tank contains liquid and vapor in equilibrium at 220 F. The distance from the bottom of the tank to the liquid level is 25 ft. What is the absolute pressure at the bottom of the tank?

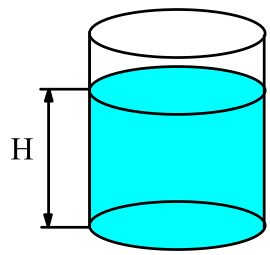
Solution:

Table F.7.1: $v_f = 0.01677\ \text{ft}^3/\text{lbm}$

$$\Delta P = \frac{g\,l}{v_f} = \frac{32.174 \times 25}{32.174 \times 0.01677 \times 144} = 10.35\ \text{lbf/in}^2$$

Since we have a two-phase mixture the vapor pressure is the saturated P_{sat} so

$$P = P_{sat} + \Delta P = 17.189 + 10.35 = \mathbf{27.54\ \ lbf/in^2}$$



3.140E

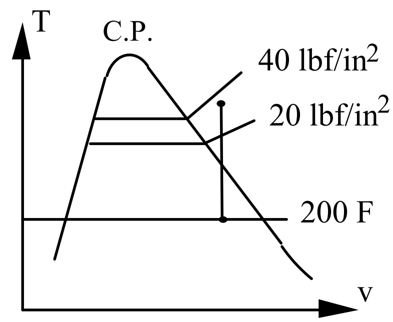
A sealed rigid vessel has volume of 35 ft^3 and contains 2 lbm of water at 200 F. The vessel is now heated. If a safety pressure valve is installed, at what pressure should the valve be set to have a maximum temperature of 400 F?

Solution:

Process: $v = V/m =$ constant

State 1: $v_1 = 35/2 = 17.5$ ft^3/lbm
from Table F.7.1
it is 2-phase

State 2: 400°F, 17.5 ft^3/lbm
Table F.7.2 between 20 and 40 lbf/in^2 so interpolate



$P \cong$ **32.4 lbf/in^2** (28.97 by software)

3.141E

You want a pot of water to boil at 220 F. How heavy a lid should you put on the 6 inch diameter pot when P_{atm} = 14.7 psia?

Solution:

Table F.7.1 at 220 F : P_{sat} = 17.189 psia

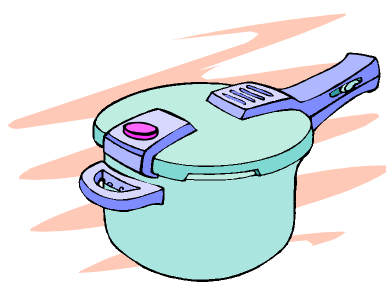
$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4}\ 6^2 = 28.274 \text{ in}^2$$

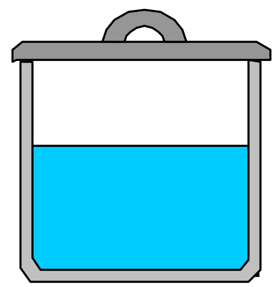
$$F_{net} = (P_{sat} - P_{atm})\ A = (17.189 - 14.7)\ (\text{lbf/ in}^2) \times 28.274 \text{ in}^2$$
$$= 70.374 \text{ lbf}$$

$$F_{net} = m_{lid}\ g$$

$$m_{lid} = F_{net}/g = \frac{70.374 \text{ lbf}}{32.174 \text{ ft/s}^2} = \frac{70.374 \times 32.174 \text{ lbm ft/s}^2}{32.174 \text{ ft/s}^2} = \mathbf{70.374\ lbm}$$

Some lids are clamped on, the problem deals with one that stays on due to its weight.





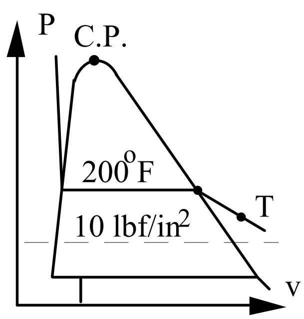
3.142E

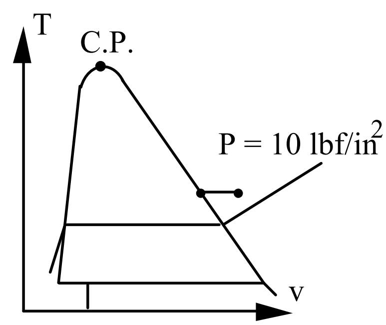
Saturated water vapor at 200 F has its pressure decreased to increase the volume by 10%, keeping the temperature constant. To what pressure should it be expanded?

Solution:

$v = 1.1 \times v_g = 1.1 \times 33.63 = 36.993 \text{ ft}^3/\text{lbm}$

Interpolate between sat. at 200 F and sup. vapor in Table F.7.2 at 200 F, 10 lbf/in^2 $\qquad$ $P \cong$ **10.54 lbf/in^2**





3.143E

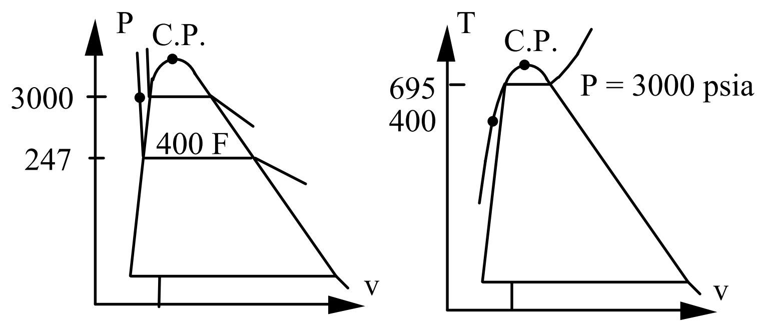
A boiler feed pump delivers 100 ft^3/min of water at 400 F, 3000 lbf/in.^{2}. What is the mass flowrate (lbm/s)? What would be the percent error if the properties of saturated liquid at 400 F were used in the calculation? What if the properties of saturated liquid at 3000 lbf/in.^{2} were used?

Solution: Table F.7.3: $v = 0.0183$ ft^3/lbm (interpolate 2000-8000 psia)

$$\dot{m} = \frac{\dot{V}}{v} = \frac{100}{60 \times 0.018334} = 91.07 \text{ lbm/s}$$

$$v_{f\,(400\text{ F})} = 0.01864 \;\Rightarrow\; \dot{m} = 89.41 \text{ lbm/s} \;\; \textbf{error 1.8\%}$$

$$v_{f\,(3000\text{ lbf/in}^2)} = 0.03475 \;\; \text{ft}^3\text{/lbm} \;\Rightarrow\; \dot{m} = 47.96 \text{ lbm/s} \;\; \textbf{error 47\%}$$



3.144E

A pressure cooker has the lid screwed on tight. A small opening with A = 0.0075 in^2 is covered with a petcock that can be lifted to let steam escape. How much mass should the petcock have to allow boiling at 250 F with an outside atmosphere at 15 psia?

Solution:

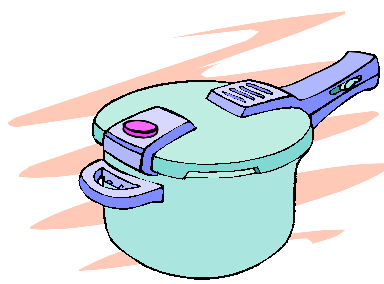
Table F.7.1 at 250 F: $P_{sat} = 29.823$ psia

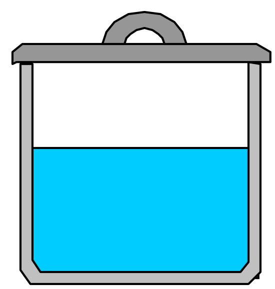
$$F_{net} = (P_{sat} - P_{atm})\ A = (29.823 - 15)\ \text{psia} \times 0.0075\ \text{in}^2 = 0.111\ \text{lbf}$$

$$F_{net} = m_{petcock}\ g$$

$$m_{petcock} = F_{net}/g = \frac{0.111\ \text{lbf}}{32.174\ \text{ft/s}^2} = \frac{0.111 \times 32.174\ \text{lbm ft/s}^2}{32.174\ \text{ft/s}^2} = \mathbf{0.111\ lbm}$$

Some petcocks are held down by a spring, the problem deals with one that stays on due to its weight.

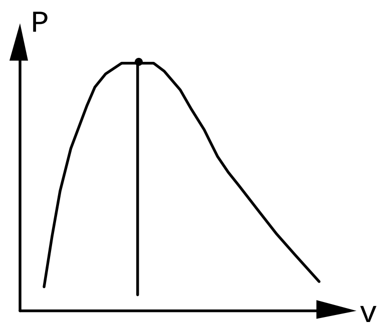




3.145E

A steel tank contains 14 lbm of propane (liquid + vapor) at 70 F with a volume of 0.25 ft^3. The tank is now slowly heated. Will the liquid level inside eventually rise to the top or drop to the bottom of the tank? What if the initial mass is 2 lbm instead of 14 lbm?

Solution:



Constant volume and mass

$v_2 = v_1 = V/m = 0.25/14 = 0.01786$ ft^3/lbm

$v_c = 3.2/44.097 = 0.07256$ ft^3/lbm

$v_2 < v_c$ so eventually sat. liquid

$\Rightarrow$ **level rises**

If $\quad v_2 = v_1 = 0.25/2 = 0.125 > v_c$

Now sat. vap. is reached so **level drops**

Ideal Gas

3.146E

A cylindrical gas tank 3 ft long, inside diameter of 8 in., is evacuated and then filled with carbon dioxide gas at 77 F. To what pressure should it be charged if there should be 2.6 lbm of carbon dioxide?

Solution:

Assume CO_2 is an ideal gas table F.4: $P = mRT/V$

$$V_{cyl} = A \times L = \frac{\pi}{4} (8)^2 \times 3 \times 12 = 1809.6 \text{ in}^3$$

$$P = \frac{2.6 \times 35.1 \times (77 + 459.67) \times 12}{1809.6} = \mathbf{324.8\ lbf/in^2}$$

3.147E

A spherical helium balloon of 30 ft in diameter is at ambient T and P, 60 F and 14.69 psia. How much helium does it contain? It can lift a total mass that equals the mass of displaced atmospheric air. How much mass of the balloon fabric and cage can then be lifted?

$$V = \frac{\pi}{6} D^3 = \frac{\pi}{6} 30^3 = 14\ 137\ \text{ft}^3$$

$$m_{He} = \rho V = \frac{V}{v} = \frac{PV}{RT}$$

$$= \frac{14.69 \times 14\ 137 \times 144}{386.0 \times 520} = 148.99\ \text{lbm}$$

$$m_{air} = \frac{PV}{RT} = \frac{14.69 \times 14\ 137 \times 144}{53.34 \times 520}$$

$$= 1078\ \text{lbm}$$

$$m_{lift} = m_{air} - m_{He} = 1078 - 149 = \mathbf{929\ lbm}$$

3.148E

Give the phase and the specific volume for each of the following.

Solution:

a. CO_2 $\quad T = 510$ F $\quad P = 75$ lbf/in.^{2} $\quad$ Table F.4

superheated vapor ideal gas

$$v = RT/P = \frac{35.1 \times (510 + 459.7)}{75 \times 144} = \mathbf{3.152\ ft^3/lbm}$$

b. Air $\quad T = 68$ F $\quad P = 2$ atm $\quad$ Table F.4

superheated vapor ideal gas

$$v = RT/P = \frac{53.34 \times (68 + 459.7)}{2 \times 14.6 \times 144} = \mathbf{6.6504\ ft^3/lbm}$$

c. Ar $T = 300$ F, $P = 30$ lbf/in.^{2} $\quad$ Table F.4

Ideal gas: $\quad v = RT/P = 38.68\ (300 + 459.7) / (30 \times 144) = \mathbf{6.802\ ft^3/lbm}$

Review Problems

3.149E

What is the percent error in specific volume if the ideal gas model is used to represent the behavior of superheated ammonia at 100 F, 80 lbf/in.^{2}? What if the generalized compressibility chart, Fig. D.1, is used instead?

Solution:

Ammonia Table F.8.2: $v = 4.186$ ft^3/lbm

Ideal gas $v = \dfrac{RT}{P} = \dfrac{90.72 \times 559.7}{80 \times 144} = 4.4076$ ft^3/lbm **5.3% error**

Generalized compressibility chart and Table D.4

$T_r = 559.7/729.9 = 0.767$, $P_r = 80/1646 = 0.0486$ => $Z \cong 0.96$

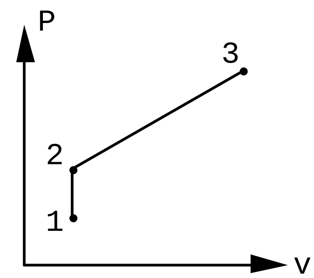
$v = ZRT/P = 0.96 \times 4.4076 = 4.231$ ft^3/lbm **1.0% error**

3.150E

A cylinder is fitted with a 4-in.-diameter piston that is restrained by a linear spring (force proportional to distance) as shown in Fig. P3.16. The spring force constant is 400 lbf/in. and the piston initially rests on the stops, with a cylinder volume of 60 in.^{3}. The valve to the air line is opened and the piston begins to rise when the cylinder pressure is 22 lbf/in.^{2}. When the valve is closed, the cylinder volume is 90 in.^{3} and the temperature is 180 F. What mass of air is inside the cylinder?

Solution: $V_1 = V_2 = 60 \text{ in}^3$; $A_p = \frac{\pi}{4} \times 4^2 = 12.566 \text{ in}^2$

$P_2 = 22 \text{ lbf/in}^2$; $V_3 = 90 \text{ in}^3$, $T_3 = 180°\text{F} = 639.7 \text{ R}$



Linear spring: $P_3 = P_2 + \frac{k_s(V_3\text{-}V_2)}{A_p^{\,2}}$

$$= 22 + \frac{400}{12.566^2}(90\text{-}60) = 98 \text{ lbf/in}^2$$

$$m = \frac{P_3V_3}{RT_3} = \frac{98 \times 90}{12 \times 53.34 \times 639.7} = \mathbf{0.02154\ lbm}$$

3.151E

A 35 ft^3 rigid tank has propane at 15 psia, 540 R and connected by a valve to another tank of 20 ft^3 with propane at 40 psia, 720 R. The valve is opened and the two tanks come to a uniform state at 600 R. What is the final pressure?

Solution:

Propane is an ideal gas ($P << P_c$) with R = 35.04 ft-lbf/lbm R from Tbl. F.4

$$m_A = \frac{P_A V_A}{RT_A} = \frac{15 \times 35 \times 144}{35.04 \times 540} = 3.995 \text{ lbm}$$

$$m = \frac{P_B V_B}{RT_B} = \frac{40 \times 20 \times 144}{35.04 \times 720} = 4.566 \text{ lbm}$$

$$V_2 = V_A + V_B = 55 \text{ ft}^3$$

$$m_2 = m_A + m_B = 8.561 \text{ lbm}$$

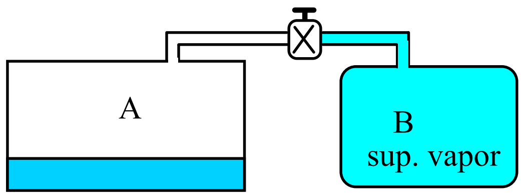
$$P_2 = \frac{m_2 RT_2}{V_2} = \frac{8.561 \times 35.04 \times 600}{55 \times 144} = \mathbf{22.726\ psia}$$

3.152E

Two tanks are connected together as shown in Fig. P3.49, both containing water. Tank A is at 30 lbf/in.^{2}, v = 8 ft^3/lbm, V = 40 ft^3 and tank B contains 8 lbm at 80 lbf/in. ^{2}, 750 F. The valve is now opened and the two come to a uniform state. Find the final specific volume.

Solution:

Control volume both tanks. Constant total volume and mass process.



State A1: (P, v) two-phase, $m_A = V_A/v_A = 40/8 = 5$ lbm

State B1: (P, T) Table F.7.2: $v_B = (8.561 + 9.322)/2 = 8.9415$

$$\Rightarrow V_B = m_B v_B = 8 \times 8.9415 = 71.532 \text{ ft}^3$$

Final state: $m_{tot} = m_A + m_B = 5 + 8 = 13$ lbm

$$V_{tot} = V_A + V_B = 111.532 \text{ ft}^3$$

$$v_2 = V_{tot}/m_{tot} = 111.532/13 = \mathbf{8.579\ ft^3/lbm}$$

3.153E

A 35 ft^3 rigid tank has air at 225 psia and ambient 600 R connected by a valve to a piston cylinder. The piston of area 1 ft^2 requires 40 psia below it to float, Fig. P3.99. The valve is opened and the piston moves slowly 7 ft up and the valve is closed. During the process air temperature remains at 600 R. What is the final pressure in the tank?

$$m_A = \frac{P_A V_A}{RT_A} = \frac{225 \times 35 \times 144}{53.34 \times 600} = 35.433 \text{ lbm}$$

$$m_{B2} - m_{B1} = \frac{\Delta V_A}{v_B} = \frac{\Delta V_B P_B}{RT} = \frac{1 \times 7 \times 40 \times 144}{53.34 \times 600} = 1.26 \text{ lbm}$$

$$m_{A2} = m_A - (m_{B2} - m_{B1}) = 35.433 - 1.26 = 34.173 \text{ lbm}$$

$$P_{A2} = \frac{m_{A2} RT}{V_A} = \frac{34.173 \times 53.34 \times 600}{35 \times 144} = \mathbf{217\ psia}$$

3.154E

Give the phase and the missing properties of P, T, v and x. These may be a little more difficult if the appendix tables are used instead of the software.

Solution:

a. R-22 at $T = 50$ F, $v = 0.6$ ft^3/lbm: Table F.9.1 $v > v_g$

sup. vap. F.9.2 interpolate between sat. and sup. vap at 50 F.

$P \cong 98.73 + (0.6 - 0.5561)(80 - 98.73)/(0.708 - 0.5561) =$ **93.3 lbf/in^2**

b. H_2O $v = 2$ ft^3/lbm, $x = 0.5$: Table F.7.1

since v_f is so small we find it approximately where $v_g = 4$ ft^3/lbm.

$v_f + v_g = 4.3293$ at 330 F, $v_f + v_g = 3.80997$ at 340 F.

linear interpolation T ≅ **336 F,** P ≅ **113 lbf/in^2**

c. H_2O $T = 150$ F, $v = 0.01632$ ft^3/lbm: Table F.7.1, $v < v_f$

compr. liquid P ≅ **500 lbf/in^2**

d. NH_3 $T = 80$ F, $P = 13$ lbf/in.^{2} Table F.8.1 P < Psat

sup. vap. interpolate between 10 and 15 psia: v = **26.97 ft^3/lbm**

v is not linear in P (more like 1/P) so computer table is more accurate.

e. R-134a $v = 0.08$ ft^3/lbm, x = 0.5: Table F.10.1

since v_f is so small we find it approximately where $v_g = 0.16$ ft^3/lbm.

$v_f + v_g = 0.1729$ at 150 F, $v_f + v_g = 0.1505$ at 160 F.

linear interpolation T ≅ **156 F,** P ≅ **300 lbf/in^2**

3.155E

A pressure cooker (closed tank) contains water at 200 F with the liquid volume being 1/10 of the vapor volume. It is heated until the pressure reaches 300 lbf/in.^{2}. Find the final temperature. Has the final state more or less vapor than the initial state?

Solution:

Process: Constant volume and mass.

$V_f = m_f v_f = V_g/10 = m_g v_g/10$; Table F.7.1: $v_f = 0.01663$, $v_g = 33.631$

$$x_1 = \frac{m_g}{m_g + m_f} = \frac{10\ m_f v_f / v_g}{m_f + 10\ m_f v_f / v_g} = \frac{10\ v_f}{10\ v_f + v_g} = \frac{0.1663}{0.1663 + 33.631} = 0.00492$$

$v_2 = v_1 = 0.01663 + x_1 \times 33.615 = 0.1820\ \text{ft}^3/\text{lbm}$

$P_2, v_2 \Rightarrow T_2 = T_{sat} = \mathbf{417.43\ F}$

$0.1820 = 0.01890 + x_2 \times 1.5286$

$x_2 = \mathbf{0.107}$ more vapor than state 1.

3.156E

Refrigerant-22 in a piston/cylinder arrangement is initially at 120 F, $x = 1$. It is then expanded in a process so that $P = Cv^{-1}$ to a pressure of 30 lbf/in.^{2}. Find the final temperature and specific volume.

Solution:

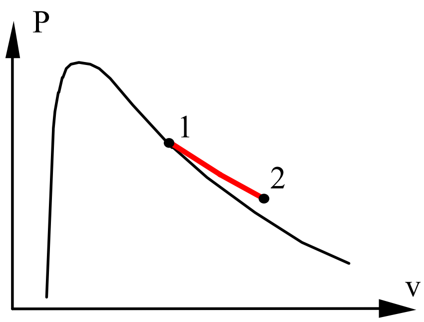
State 1: $P_1 = 274.6$ lbf/in^2 $\quad v_1 = 0.1924$ ft^3/lbm

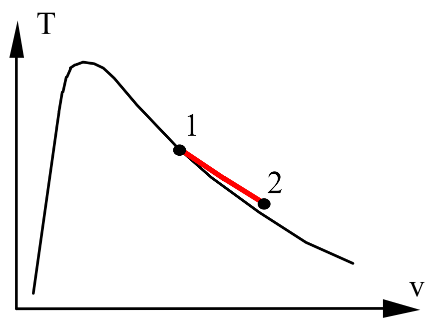
Process: $Pv = C = P_1v_1 = P_2v_2$

State 2: $P_2 = 30$ lbf/in^2 and on process line (equation).

$$v_2 = \frac{v_1P_1}{P_2} = 0.1924 \times 274.6/30 = \mathbf{1.761\ ft^3/lbm}$$

Table F.9.2 between saturated at -11.71 F and 0 F: $\quad T_2 \cong$ **-8.1 F**





Compressiblity Factor

3.157E

A substance is at 70 F, 300 lbf/in.^{2} in a 10 ft^3 tank. Estimate the mass from the compressibility chart if the substance is a) air, b) butane or c) propane.

Solution:

Use Fig. D.1 for compressibility Z and table F.1 for critical properties

$$m = \frac{PV}{ZRT} = \frac{300 \times 144 \times 10}{530\ ZR} = \frac{815.09}{ZR}$$

Air use nitrogen $P_c = 492$ lbf/in.^{2}; $T_c = 227.2$ R

$P_r = 0.61$; $T_r = 2.33$; $Z = 0.98$

$$m = \frac{PV}{ZRT} = \frac{815.09}{ZR} = \frac{815.09}{0.98 \times 55.15} = \mathbf{15.08\ lbm}$$

Butane $P_c = 551$ lbf/in.^{2}; $T_c = 765.4$ R

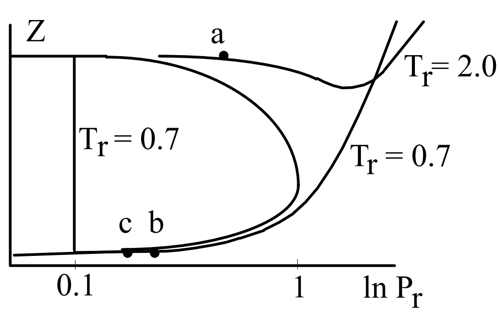
$P_r = 0.544$; $T_r = 0.692$; $Z = 0.09$

$$m = \frac{PV}{ZRT} = \frac{815.09}{ZR} = \frac{815.09}{0.09 \times 26.58} = \mathbf{340.7\ lbm}$$

Propane $P_c = 616$ lbf/in.^{2}; $T_c = 665.6$ R

$P_r = 0.487$; $T_r = 0.796$; $Z = 0.08$

$$m = \frac{PV}{ZRT} = \frac{815.09}{ZR} = \frac{815.09}{0.08 \times 35.04} = \mathbf{290.8\ lbm}$$



3.158E

Determine the mass of an ethane gas stored in a 25 ft^3 tank at 250 F, 440 $lbf/in.^2$ using the compressibility chart. Estimate the error (%) if the ideal gas model is used.

Solution

Table F.1: $T_r = (250 + 460) / 549.7 = 1.29$ and $P_r = 440/708 = 0.621$

Figure D.1 $\Rightarrow$ $Z = 0.9$

$m = PV/ZRT = 440 \times 144 \times 25 / (51.38 \times 710 \times 0.9) =$ **48.25 lbm**

Ideal gas Z = 1 $\Rightarrow$ m = 43.21 lbm **10% error**