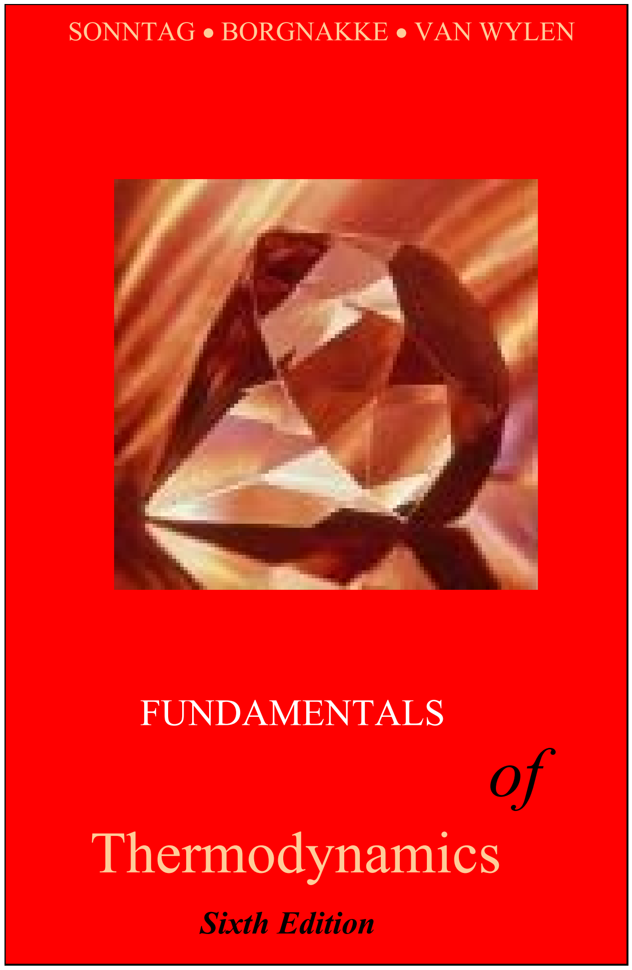
SOLUTION MANUAL
ENGLISH UNIT PROBLEMS
CHAPTER 12



CHAPTER 12

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Correspondence List

The correspondence between the new English unit problem set and the previous 5th edition chapter 12 problem set.

New	5th	SI	New	5th	SI	New	5th	SI
134	new	4	146	84	39	158	new	78
135	new	5	147	85	40	159	94	85
136	new	6	148	new	43	160	new	80
137	new	7	149	89	51	161	95	86
138	new	8	150	90a	53	162	96	87
139	new	9	151	88	55	163	97	89
140	new	10	152	86	62	164	99	92
141	new	16	153	87	66	165	new	98
142	81	21	154	91	68	166	98	102
143	82	26	155	92	72	167	100	105
144	new	30	156	90b	-	168	101	115
145	83	34	157	93	76	169	103	127
						170	102	130

Concept Problems

12.134E

If oxygen is 21% by mole of air, what is the oxygen state (P, T, v) in a room at 540 R, 15 psia of total volume 2000 ft^3?

The temperature is 540 R,

The partial pressure is $P_{O2} = yP_{tot} = 3.15$ psia.

At this T, P: $v = RT/P = \frac{48.28 \times 540}{3.15 \times 144} \frac{(\text{ft-lbf/lbm R}) \times \text{R}}{(\text{lbf/in}^2)\ (\text{in/ft})^2} = 57.48\ \text{ft}^3/\text{lbm}$

12.135E

A flow of oxygen and one of nitrogen, both 540 R, are mixed to produce 1 lbm/s air at 540 R, 15 psia. What are the mass and volume flow rates of each line?

For the mixture, $M = 0.21 \times 32 + 0.79 \times 28.013 = 28.85$

For O_2 , $c = 0.21 \times 32 / 28.85 = 0.2329$

For N_2 , $c = 0.79 \times 28.013 / 28.85 = 0.7671$

Since the total flow out is 1 lbm/s, these are the component flows in lbm/s.
Volume flow of O_2 in is

$$\dot{V} = c\dot{m}v = c\dot{m}\frac{RT}{P} = 0.2329 \times \frac{48.28 \times 540}{15 \times 144} = \mathbf{2.81\ ft^3/s}$$

Volume flow of N_2 in is

$$\dot{V} = c\dot{m}v = c\dot{m}\frac{RT}{P} = 0.7671 \times \frac{55.15 \times 540}{15 \times 144} = \mathbf{10.58\ ft^3/s}$$

12.136E

A flow of gas A and a flow of gas B are mixed in a 1:1 mole ratio with same T. What is the entropy generation per kmole flow out?

For this each mole fraction is one half so,

Eq. 12.19: $\Delta S = -\bar{R}(0.5 \ln 0.5 + 0.5 \ln 0.5) = +0.6931\ \bar{R}$

$= 0.6931 \times 1.98589 = \mathbf{1.376\ Btu/lbmol\text{-}R}$

12.137E

A rigid container has 1 lbm argon at 540 R and 1 lbm argon at 720 R both at 20 psia. Now they are allowed to mix without any external heat transfer. What is final T, P? Is any s generated?

Energy Eq.: $U_2 - U_1 = 0 = 2mu_2 - mu_{1a} - mu_{1b} = mC_v(2T_2 - T_{1a} - T_{1b})$

$$T_2 = (T_{1a} + T_{1b})/2 = 630 \text{ R},$$

Process Eq.: V = constant =>

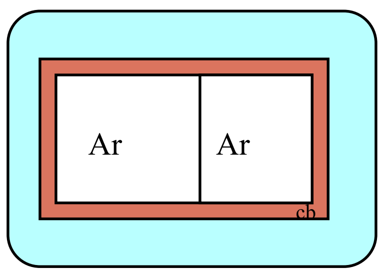
$$P_2V = 2mRT_2 = mR(T_{1a} + T_{1b}) = P_1V_{1a} + P_1V_{1b} = P_1V$$

$$P_2 = P_1 = 20 \text{ psia}$$

ΔS due to temp changes only , not P

$$\Delta S = m\,(s_2 - s_{1a}) + m\,(s_2 - s_{1b}) = mC\,[\,\ln (T_2/T_{1a}) + \ln (T_2/T_{1b})\,]$$

$$= 1 \times 0.124 \left[\ \ln \frac{630}{540} + \ln \frac{630}{720} \right] = 0.00256 \text{ Btu/R}$$



12.138E

A rigid container has 1 lbm CO_2 at 540 R and 1 lbm argon at 720 R both at 20 psia. Now they are allowed to mix without any heat transfer. What is final T, P?

No Q, No W so the energy equation gives constant U

$$\Delta U = 0 = (1\times0.201 + 1\times0.124) \times T_2 - 1\times0.201\times540 - 1\times0.124\times720$$

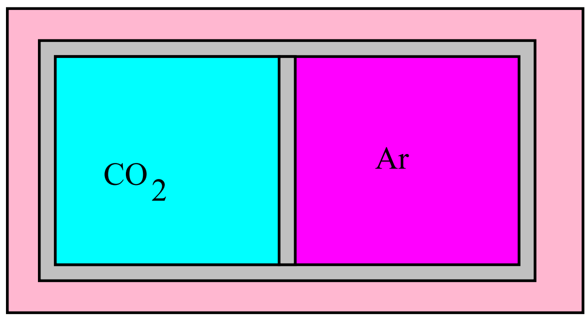
$$T_2 = 608.7 \text{ R},$$

Volume from the beginning state

$$V = [1\times35.10\times540/20 + 1\times38.68\times720/20\ ]/144 = 16.25 \text{ ft}^3$$

Pressure from ideal gas law and Eq.12.15 for R

$$P_2 = (1\times35.10 + 1\times38.68) \times 608.7/(16.25 \times144) = 19.2 \text{ psia}$$



12.139E

A flow of 1 lbm/s argon at 540 R and another flow of 1 lbm/s CO_2 at 2800 R both at 20 psia are mixed without any heat transfer. What is the exit T, P?

No work implies no pressure change for a simple flow. The energy equation becomes

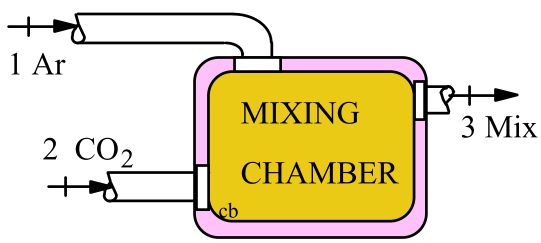
$$\dot{m}h_i = \dot{m}h_e = (\dot{m}h_i)_{Ar} + (\dot{m}h_i)_{CO2} = (\dot{m}h_e)_{Ar} + (\dot{m}h_e)_{CO2}$$

$$\Rightarrow \quad \dot{m}_{CO2}C_{p\ CO2}(T_e - T_i)_{CO2} + \dot{m}_{Ar}C_{p\ Ar}(T_e - T_i)_{Ar} = 0$$

$$\Rightarrow \quad \dot{m}_{Ar}C_{p\ Ar}T_i + \dot{m}_{CO2}C_{p\ CO2}T_i = [\dot{m}_{Ar}C_{p\ Ar} + \dot{m}_{CO2}C_{p\ CO2}]\ T_e$$

$$1 \times 0.124 \times 540 + 1 \times 0.201 \times 2800 = (1 \times 0.124 + 1 \times 0.201) \times T_2$$

T_2 = **1937.7 R** $\qquad$ **P_2 = 20 psia**



12.140E

What is the rate of entropy increase in problem 12.139?

Using Eq. 12.4, the mole fraction of CO_2 in the mixture is 0.4758.
From Eqs. 12.16 and 12.17, from the two inlet states to state 2,

$$\Delta S = 1\times[0.124 \ln(\frac{1937.7}{540}) - \frac{38.68}{778} \ln(\frac{0.5242\times20}{20})]$$

$$+1\times[0.201 \ln(\frac{1937.7}{2800}) - \frac{35.10}{778} \ln(\frac{0.4758\times20}{20})] = \mathbf{0.15\ Btu/s\ R}$$

12.141E

If I have air at 14.7 psia and a) 15 F b) 115 F and c) 230 F what is the maximum absolute humidity I can have?

Humidity is related to relative humidity (max 100%) and the pressures as in Eq.12.28 where from Eq.12.25 $P_v = \Phi\ P_g$ and $P_a = P_{tot} - P_v$.

$$\omega = 0.622\ \frac{P_v}{P_a} = 0.622\ \frac{\Phi\ P_g}{P_{tot} - \Phi P_g}$$

a) $\omega = 0.622 \times 0.2601/99.74 = 0.001\ 62$
b) $\omega = 0.622 \times 9.593/90.407 = 0.0660$
c) $P_g = 20.78$ psia, no max ω for $P > 14.7$ psia

Mixture Composition and Properties

12.142E

A gas mixture at 250 F, 18 lbf/in.^{2} is 50% N_2, 30% H_2O and 20% O_2 on a mole basis. Find the mass fractions, the mixture gas constant and the volume for 10 lbm of mixture.

From Eq. 12.3: $c_i = y_i\ M_i / \sum y_j M_j$

$M_{MIX} = \sum y_j M_j = 0.5 \times 28.013 + 0.3 \times 18.015 + 0.2 \times 31.999$

$= 14.0065 + 5.4045 + 6.3998 = 25.811$

$c_{N2} = 14.0065 / 25.811 = 0.5427$, $c_{H2O} = 5.4045 / 25.811 = 0.2094$

$c_{O2} = 6.3998 / 25.811 = 0.2479$, sums to 1 OK

$R_{MIX} = \bar{R}/M_{MIX} = 1545.36 / 25.811 =$ **59.87 lbf ft/lbm R**

$V = mR_{MIX}\ T/P = 10 \times 59.87 \times 710 / (18 \times 144) =$ **164 ft^3**

12.143E

Weighing of masses gives a mixture at 80 F, 35 lbf/in.^{2} with 1 lbm O_2, 3 lbm N_2 and 1 lbm CH_4. Find the partial pressures of each component, the mixture specific volume (mass basis), mixture molecular weight and the total volume.

From Eq. 12.4: $y_i = (m_i / M_i) / \sum m_j/M_j$

$n_{tot} = \sum m_j/M_j = (1/31.999) + (3/28.013) + (1/16.04)$

$= 0.031251 + 0.107093 + 0.062344 = 0.200688$

$y_{O2} = 0.031251/0.200688 = 0.1557$, $\quad y_{N2} = 0.107093/0.200688 = 0.5336$,

$y_{CH4} = 0.062344/0.200688 = 0.3107$

$P_{O2} = y_{O2}\, P_{tot} = 0.1557 \times 35 =$ **5.45 lbf/in.^{2}**,

$P_{N2} = y_{N2}\, P_{tot} = 0.5336 \times 35 =$ **18.676 lbf/in.^{2}**,

$P_{CH4} = y_{CH4}\, P_{tot} = 0.3107 \times 35 =$ **10.875 lbf/in.^{2}**

$V_{tot} = n_{tot}\, \bar{R}T/P = 0.200688 \times 1545 \times 539.7 / (35 \times 144) =$ **33.2 ft^3**

$v = V_{tot}/m_{tot} = 33.2 / (1 + 3 + 1) =$ **6.64 ft^3/lbm**

$M_{MIX} = \sum y_j M_j = m_{tot}/n_{tot} = 5/0.200688 =$ **24.914**

12.144E

A new refrigerant R-410a is a mixture of R-32 and R-125 in a 1:1 mass ratio. What is the overall molecular weight, the gas constant and the ratio of specific heats for such a mixture?

Eq.12.15:

$R_{mix} = \sum c_i R_i = 0.5 \times 29.7 + 0.5 \times 12.87 =$ **21.285 ft-lbf/lbm R**

Eq.12.23:

$C_{P\ mix} = \sum c_i\ C_{P\ i} = 0.5 \times 0.196 + 0.5 \times 0.189 = 0.1925$ Btu/lbm R

Eq.12.21:

$C_{V\ mix} = \sum c_i C_{V\ i} = 0.5 \times 0.158 + 0.5 \times 0.172 = 0.165$ Btu/lbm R

$(= C_{P\ mix} - R_{mix})$

$k_{mix} = C_{P\ mix} / C_{V\ mix} = 0.1925 / 0.165 =$ **1.1667**

$M = \sum y_j M_j = = 1 / \sum (c_j / M_j) = \dfrac{1}{\dfrac{0.5}{52.024} + \dfrac{0.5}{120.022}} =$ **72.586**

Simple Processes

12.145E

A pipe flows 1.5 lbm/s mixture with mass fractions of 40% CO_2 and 60% N_2 at 60 lbf/in.^{2}, 540 R. Heating tape is wrapped around a section of pipe with insulation added and 2 Btu/s electrical power is heating the pipe flow. Find the mixture exit temperature.

Solution:

C.V. Pipe heating section. Assume no heat loss to the outside, ideal gases.

Energy Eq.: $\dot{Q} = \dot{m}(h_e - h_i) = \dot{m}C_{P\ mix}(T_e - T_i)$

From Eq.12.23

$$C_{P\ mix} = \sum c_i\ C_i = 0.4 \times 0.201 + 0.6 \times 0.249 = 0.2298 \text{ Btu/lbm R}$$

Substitute into energy equation and solve for exit temperature

$$T_e = T_i + \dot{Q}\ /\ \dot{m}C_{P\ mix} = 540 + 2/(1.5 \times 0.2298) = \mathbf{545.8\ R}$$

12.146E

An insulated gas turbine receives a mixture of 10% CO_2, 10% H_2O and 80% N_2 on a mass basis at 1800 R, 75 lbf/in.^{2}. The volume flow rate is 70 ft^3/s and its exhaust is at 1300 R, 15 lbf/in.^{2}. Find the power output in Btu/s using constant specific heat from F.4 at 540 R.

C.V. Turbine, Steady, 1 inlet, 1 exit flow with an ideal gas mixture, q = 0.

Energy Eq.: $\dot{W}_T = \dot{m}(h_i - h_e) = \dot{n}(\bar{h}_i - \bar{h}_e) = \dot{n}\bar{C}_{P\,mix}(T_i - T_e)$

$$PV = n\bar{R}T \quad => \quad \dot{n} = \frac{P\dot{V}}{\bar{R}T} = \frac{75 \times 144 \times 70}{1545.4 \times 1800} = 0.272 \text{ lbmol/s}$$

$$\bar{C}_{P\,mix} = \sum y_i \bar{C}_i = 0.1 \times 44.01 \times 0.201 + 0.1 \times 18.015 \times 0.447$$
$$+ 0.8 \times 28.013 \times 0.249 = 7.27 \text{ Btu/lbmol R}$$

$\dot{W}_T = 0.272 \times 72.7 \times (1800 - 1300) =$ **988.7 Btu/s**

12.147E

Solve Problem 12.146 using the values of enthalpy from Table F.6

C.V. Turbine, Steady, 1 inlet, 1 exit flow with an ideal gas mixture, q = 0.

Energy Eq.: $\dot{W}_T = \dot{m}(h_i - h_e) = \dot{n}(\bar{h}_i - \bar{h}_e)$

$$PV = n\bar{R}T \quad => \quad \dot{n} = \frac{P\dot{V}}{\bar{R}T} = \frac{75 \times 144 \times 70}{1545.4 \times 1800} = 0.272 \text{ lbmol/s}$$

$$\dot{W}_T = 0.272 \times [0.1(14\,358 - 8121) + 0.1(11\,178 - 6468.5) + 0.8(9227 - 5431)]$$

$= \mathbf{1123.7\ Btu/s}$

12.148E

A piston cylinder device contains 0.3 lbm of a mixture of 40% methane and 60% propane by mass at 540 R and 15 psia. The gas is now slowly compressed in an isothermal (T = constant) process to a final pressure of 40 psia. Show the process in a P-V diagram and find both the work and heat transfer in the process.

Solution:

C.V. Mixture of methane and propane, this is a control mass.

Assume methane & propane are ideal gases at these conditions.

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

Property from Eq.12.15

$$R_{mix} = 0.4\ R_{CH4} + 0.6\ R_{C3H8}$$

$$= 0.4 \times 96.35 + 0.6 \times 35.04 = 59.564\ \frac{\text{ft-lbf}}{\text{lbm R}} = 0.07656\ \frac{\text{Btu}}{\text{lbm R}}$$

Process: T = constant & ideal gas =>

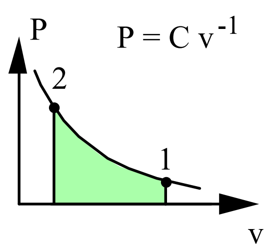
$${}_1W_2 = \int P\,dV = mR_{mix}T \int (1/V)dV = mR_{mix}T \ln (V_2/V_1)$$

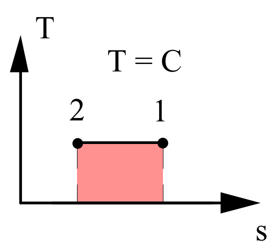
$$= mR_{mix}T \ln (P_1/P_2)$$

$$= 0.3 \times 0.07656 \times 540 \ln (15/40) = \mathbf{-12.16\ Btu}$$

Now heat transfer from the energy equation where we notice that u is a constant (ideal gas and constant T) so

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = {}_1W_2 = \mathbf{-12.16\ Btu}$$





12.149E

A mixture of 4 lbm oxygen and 4 lbm of argon is in an insulated piston cylinder arrangement at 14.7 lbf/in.^{2}, 540 R. The piston now compresses the mixture to half its initial volume. Find the final pressure, temperature and the piston work.

Since $T_1 >> T_C$ assume ideal gases.

Energy Eq.: $u_2 - u_1 = {}_1q_2 - {}_1w_2 = -\,{}_1w_2$; Entropy Eq.: $s_2 - s_1 = 0$

Process Eq.: Pv^k = constant, $v_2 = v_1/2$

$$P_2 = P_1(v_1/v_2)^k = P_1(2)^k; \;\; T_2 = T_1(v_1/v_2)^{k-1} = T_1(2)^{k-1}$$

Find k_{mix} to get P_2, T_2 and $C_{v\,mix}$ for $u_2 - u_1$

$R_{mix} = \Sigma c_i R_i = (0.5 \times 48.28 + 0.5 \times 38.68)/778 = 0.055887$ Btu/lbm R

$C_{Pmix} = \Sigma c_i C_{Pi} = 0.5 \times 0.219 + 0.5 \times 0.1253 = 0.17215$ Btu/lbm R

$C_{vmix} = C_{Pmix} - R_{mix} = 0.11626$, $k_{mix} = C_{Pmix}/C_{vmix} = 1.4807$

$P_2 = 14.7(2)^{1.4805} = 41.03$ lbf/in^2, $T_2 = 540 \times 2^{0.4805} = 753.5$ R

${}_1w_2 = u_1 - u_2 = C_v(T_1 - T_2) = 0.11626\,(540 - 753.5) = -24.82$ Btu/lbm

${}_1W_2 = m_{tot}\,{}_1w_2 = 8\,(-24.82) =$ **-198.6 Btu**

12.150E

Two insulated tanks A and B are connected by a valve. Tank A has a volume of 30 ft^3 and initially contains argon at 50 lbf/in.^{2}, 50 F. Tank B has a volume of 60 ft^3 and initially contains ethane at 30 lbf/in.^{2}, 120 F. The valve is opened and remains open until the resulting gas mixture comes to a uniform state. Find the final pressure and temperature.

Energy eq.: $U_2\text{-}U_1 = 0 = n_{Ar}\bar{C}_{V0}(T_2\text{-}T_{A1}) + n_{C_2H_6}\bar{C}_{VO}(T_2\text{-}T_{B1})$

$$n_{Ar} = P_{A1}V_A/\bar{R}T_{A1} = \frac{50\times 144\times 30}{1545\times 509.7} = 0.2743 \text{ lbmol}$$

$$n_{C_2H_6} = P_{B1}V_B/\bar{R}T_{B1} = \frac{30\times 144\times 60}{1545\times 579.7} = 0.2894 \text{ lbmol}$$

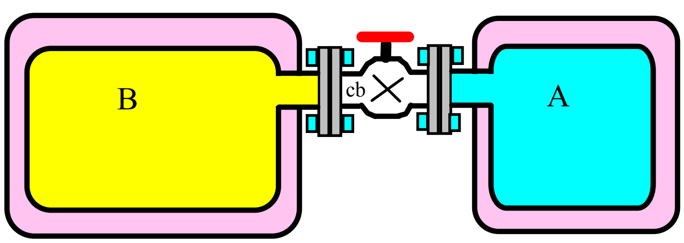
$$n_2 = n_{Ar} + n_{C_2H_6} = 0.5637 \text{ lbmol}$$

Substitute this into the energy equation

$$0.2743 \times 39.948 \times 0.0756\ (T_2 - 509.7)$$
$$+ 0.2894 \times 30.07 \times 0.361\ (T_2 - 509.7) = 0$$

Solving, $T_2 = \mathbf{565.1\ R}$

$$P_2 = n_2\bar{R}T_2/(V_A+V_B) = \frac{0.5637\times 1545\times 565.1}{90\times 144} = \mathbf{38\ lbf/in^2}$$



12.151E

A mixture of 50% carbon dioxide and 50% water by mass is brought from 2800 R, 150 lbf/in.^{2} to 900 R, 30 lbf/in.^{2} in a polytropic process through a steady flow device. Find the necessary heat transfer and work involved using values from F.4.

Process Pv^n = constant leading to

$n \ln(v_2/v_1) = \ln(P_1/P_2)$; $v = RT/P$

$n = \ln(150/30) / \ln(900 \times 150/30 \times 2800) = 3.3922$

$R_{mix} = \Sigma c_i R_i = (0.5 \times 35.1 + 0.5 \times 85.76)/778 = 0.07767$ Btu/lbm R

$C_{P\,mix} = \Sigma c_i C_{Pi} = 0.5 \times 0.203 + 0.5 \times 0.445 = 0.324$ Btu/lbm R

$$w = -\int v dP = -\frac{n}{n-1}(P_e v_e - P_i v_i) = -\frac{nR}{n-1}(T_e - T_i)$$

$$= -\frac{3.3922 \times 0.07767}{2.3922}(900 - 2800) = \mathbf{209.3\ \frac{Btu}{lbm}}$$

$q = h_e - h_i + w = C_P(T_e - T_i) + w =$ **-406.3 Btu/lbm**

Entropy Generation

12.152E

Carbon dioxide gas at 580 R is mixed with nitrogen at 500 R in an insulated mixing chamber. Both flows are at 14.7 lbf/in.^{2} and the mole ratio of carbon dioxide to nitrogen is 2:1. Find the exit temperature and the total entropy generation per mole of the exit mixture.

CV mixing chamber, Steady flow. The inlet ratio is $\dot{n}_{CO2} = 2\ \dot{n}_{N2}$ and assume no external heat transfer, no work involved.

$$\dot{n}_{CO_2} + 2\dot{n}_{N_2} = \dot{n}_{ex} = 3\dot{n}_{N_2}; \quad \dot{n}_{N_2}(\bar{h}_{N_2} + 2\bar{h}_{CO_2}) = 3\dot{n}_{N_2}\bar{h}_{mix\ ex}$$

Take 540 R as reference and write $\bar{h} = \bar{h}_{540} + \bar{C}_{Pmix}(T\text{-}540)$.

$$\bar{C}_{P\ N_2}(T_{i\ N_2}-540) + 2\bar{C}_{P\ CO_2}(T_{i\ CO_2}-540) = 3\bar{C}_{P\ mix}(T_{mix\ ex}-540)$$

$$\bar{C}_{P\ mix} = \sum y_i\bar{C}_{P\ i} = (29.178 + 2\times37.05)/3 = 8.2718\ \text{Btu/lbmol R}$$

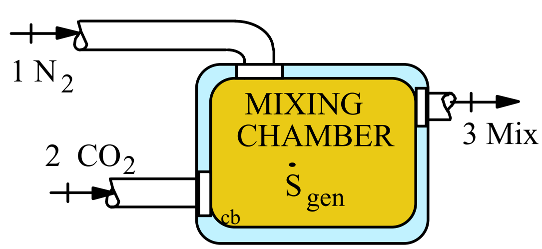
$$3\bar{C}_{P\ mix}T_{mix\ ex} = \bar{C}_{P\ N_2}T_{i\ N_2} + 2\bar{C}_{P\ CO_2}T_{i\ CO_2} = 13\ 837\ \text{Btu/lbmol}$$

$$T_{mix\ ex} = 557.6\ \text{R}; \quad P_{ex\ N_2} = P_{tot}/3; \quad P_{ex\ CO_2} = 2P_{tot}/3$$

$$\dot{S}_{gen} = \dot{n}_{ex}\bar{s}_{ex} - (\dot{n}\bar{s})_{iCO_2} - (\dot{n}\bar{s})_{iN_2} = \dot{n}_{N_2}(\bar{s}_e - \bar{s}_i)_{N_2} + 2\dot{n}_{N_2}(\bar{s}_e - \bar{s}_i)_{CO_2}$$

$$\dot{S}_{gen}/\dot{n}_{N_2} = \bar{C}_{PN_2}\ln\frac{T_{ex}}{T_{iN_2}} - \bar{R}\ln y_{N_2} + 2\bar{C}_{PCO_2}\ln\frac{T_{ex}}{T_{iCO_2}} - 2\ \bar{R}\ln y_{CO_2}$$

$$= 0.7575 + 2.1817 - 0.7038 + 1.6104 = \mathbf{3.846\ Btu/lbmol\ N_2\ R}$$



12.153E

A mixture of 60% helium and 40% nitrogen by mole enters a turbine at 150 lbf/in.^{2}, 1500 R at a rate of 4 lbm/s. The adiabatic turbine has an exit pressure of 15 lbf/in.^{2} and an isentropic efficiency of 85%. Find the turbine work.

Assume ideal gas mixture and take CV as turbine.

Energy Eq. ideal turbine: $w_{T\,s} = h_i - h_{es}$,

Entropy Eq. ideal turbine: $s_{es} = s_i \quad \Rightarrow \quad T_{es} = T_i(P_e/P_i)^{(k-1)/k}$

$\bar{C}_{P\,mix} = 0.6\times 1.25\times 4.003 + 0.4\times 0.248\times 28.013 = 5.7811$ Btu/lbmol R

$(k\text{-}1)/k = \bar{R}/\bar{C}_{P\,mix} = 1545/(5.7811\times 778) = 0.3435$

$M_{mix} = 0.6 \times 4.003 + 0.4 \times 28.013 = 13.607$,

$C_P = \bar{C}_P/M_{mix} = 0.4249$ Btu/lbm R

$T_{es} = 1500(15/150)^{0.3435} = 680$ R, $w_{Ts} = C_P(T_i\text{-}T_{es}) = 348.4$ Btu/lbm

Then do the actual turbine

$w_{T\,ac} = \eta w_{Ts} = 296.1$ Btu/lbm; $\dot{W} = \dot{m} w_{Ts} =$ **1184 Btu/s**

12.154E

A large air separation plant takes in ambient air (79% N_2, 21% O_2 by volume) at 14.7 lbf/in.^{2}, 70 F, at a rate of 2 lb mol/s. It discharges a stream of pure O_2 gas at 30 lbf/in.^{2}, 200 F, and a stream of pure N_2 gas at 14.7 lbf/in.^{2}, 70 F. The plant operates on an electrical power input of 2000 kW. Calculate the net rate of entropy change for the process.

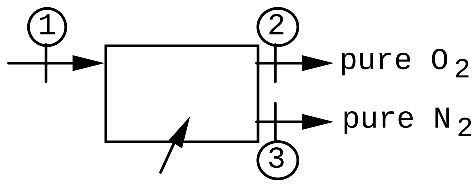
Air 79 % N_2

21 % O_2

$P_1 = 14.7$

$T_1 = 70$ F

$\dot{n}_1 = 2$ lbmol/s



$-\dot{W}_{IN} = 2000$ kW

$P_2 = 30$

$T_2 = 200$ F

$P_3 = 14.7$

$T_3 = 70$ F

$$\frac{dS_{NET}}{dt} = -\frac{\dot{Q}_{CV}}{T_0} + \sum_i \dot{n}_i \Delta\bar{s}_i = -\frac{\dot{Q}_{CV}}{T_0} + (\dot{n}_2\bar{s}_2 + \dot{n}_3\bar{s}_3 - \dot{n}_1\bar{s}_1)$$

$$\dot{Q}_{CV} = \Sigma\dot{n}\Delta\bar{h}_i + \dot{W}_{CV} = \dot{n}_{O_2}\bar{C}_{P0\,O_2}(T_2\text{-}T_1) + \dot{n}_{N_2}\bar{C}_{P0\,N_2}(T_3\text{-}T_1) + \dot{W}_{CV}$$

$$= 0.21\times2\times[32\times0.213\times(200\text{-}70)] + 0 - 2000\times3412/3600$$

$$= +382.6 - 1895.6 = -1513 \text{ Btu/s}$$

$$\Sigma\dot{n}_i\Delta\bar{s}_i = 0.21\times2\left[32\times0.219 \ln\frac{660}{530} - \frac{1545}{778}\ln\frac{30}{0.21\times14.7}\right]$$

$$+ 0.79\times2\left[0 - \frac{1545}{778}\ln\frac{14.7}{0.79\times14.7}\right]$$

$$= -1.9906 \text{ Btu/R s}$$

$$\frac{dS_{NET}}{dt} = +\frac{1513}{530} - 1.9906 = \mathbf{0.864\ Btu/R\ s}$$

12.155E

A tank has two sides initially separated by a diaphragm. Side A contains 2 lbm of water and side B contains 2.4 lbm of air, both at 68 F, 14.7 lbf/in.^{2}. The diaphragm is now broken and the whole tank is heated to 1100 F by a 1300 F reservoir. Find the final total pressure, heat transfer, and total entropy generation.

$U_2 - U_1 = m_a(u_2-u_1)_a + m_v(u_2-u_1)_v = {}_1Q_2$

$S_2 - S_1 = m_a(s_2-s_1)_a + m_v(s_2-s_1)_v = \int {}_1Q_2/T + S_{gen}$

$V_2 = V_A + V_B = m_v v_{v1} + m_a v_{a1} = 0.0321 + 31.911 = 31.944 \text{ ft}^3$

$v_{v2} = V_2/m_v = 15.9718, \;\; T_2 \Rightarrow \;\; P_{2v} = 58.7 \text{ lbf/in}^2$

$v_{a2} = V_2/m_a = 13.3098, \;\; T_2 \Rightarrow \;\; P_{2a} = mRT_2/V_2 = 43.415 \text{ lbf/in}^2$

$P_{2tot} = P_{2v} + P_{2a} = \mathbf{102 \text{ lbf/in}^2}$

Water: $u_1 = 36.08$ Btu/lbm, $u_2 = 1414.3$ Btu/lbm,

$s_1 = 0.0708$ Btu.lbm R, $s_2 = 2.011$ Btu/lbm R

Air: $u_1 = 90.05$ Btu/lbm, $u_2 = 278.23$ Btu/lbm,

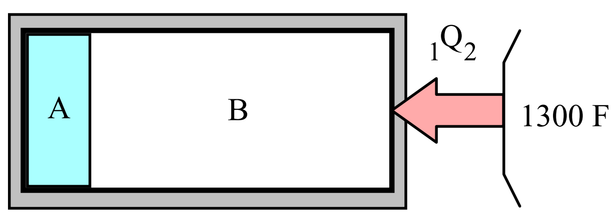
$s_{T1} = 1.6342$ Btu/lbm R, $s_{T2} = 1.9036$ Btu/lbm R

${}_1Q_2 = 2(1414.3 - 36.08) + 2.4(278.23 - 90.05) = \mathbf{3208 \text{ Btu}}$

$S_{gen} = 2(2.011-0.0708) + 2.4[1.9036 - 1.6342$

$- (53.34/778)\times\ln(43.415/14.7)] - 3208/1760$

$= 3.8804 + 0.4684 - 1.823 = \mathbf{2.526 \text{ Btu/R}}$



12.156E

Find the entropy generation for the process in Problem 12.150E.

Energy eq. $U_2 - U_1 = 0 = n_{Ar}\bar{C}_{V0}(T_2 - T_{A1}) + n_{C_2H_6}\bar{C}_{VO}(T_2 - T_{B1})$

$$n_{Ar} = P_{A1}V_A/\bar{R}T_{A1} = \frac{50\times144\times30}{1545\times509.7} = 0.2743 \text{ lbmol}$$

$$n_{C_2H_6} = P_{B1}V_B/\bar{R}T_{B1} = \frac{30\times144\times60}{1545\times579.7} = 0.2894 \text{ lbmol}$$

$$n_2 = n_{Ar} + n_{C_2H_6} = 0.5637 \text{ lbmol}$$

Substitute into energy equation

$$0.2743 \times 39.948 \times 0.0756\ (T_2 - 509.7)$$
$$+ 0.2894 \times 30.07 \times 0.361\ (T_2 - 509.7) = 0$$

Solving, T_2 = **565.1 R**

$$P_2 = n_2\bar{R}T_2/(V_A+V_B) = \frac{0.5637\times1545\times565.1}{90\times144} = \mathbf{38\ lbf/in^2}$$

$$\Delta S_{SURR} = 0 \quad \rightarrow \Delta S_{NET} = \Delta S_{SYS} = n_{Ar}\Delta\bar{S}_{Ar} + n_{C_2H_6}\Delta\bar{S}_{C_2H_6}$$

$$y_{Ar} = 0.2743/0.5637 = 0.4866$$

$$\Delta\bar{S}_{Ar} = \bar{C}_{P\ Ar} \ln\frac{T_2}{T_{A1}} - \bar{R}\ln\frac{y_{Ar}P_2}{P_{A1}}$$

$$= 39.948\times0.1253 \ln\frac{565.1}{509.7} - \frac{1545}{778}\ln\frac{0.4866\times38}{50} = 2.4919 \text{ Btu/lbmol R}$$

$$\Delta\bar{S}_{C_2H_6} = \bar{C}_{C_2H_6}\ln\frac{T_2}{T_{B1}} - \bar{R}\ln\frac{y_{C_2H_6}P_2}{P_{B1}}$$

$$= 30.07\times0.427 \ln\frac{565.1}{579.7} - \frac{1545}{778}\ln\frac{0.5134\times38}{30}$$

$$= 0.5270 \text{ Btu/lbmol R}$$

$$\Delta S_{NET} = 0.2743\times2.4919 + 0.2894\times0.5270 = \mathbf{0.836\ Btu/R}$$

Air Water vapor Mixtures

12.157E

Consider a volume of 2000 ft^3 that contains an air-water vapor mixture at 14.7 lbf/in.^{2}, 60 F, and 40% relative humidity. Find the mass of water and the humidity ratio. What is the dew point of the mixture?

Air-vap P = 14.7 lbf/in.^{2}, T = 60 F, ϕ = 40%

$P_g = P_{sat60} = 0.256$ lbf/in.^{2}

$P_v = \phi\, P_g = 0.4 \times 0.256 = 0.1024$ lbf/in.^{2}

$$m_{v1} = \frac{P_v V}{R_v T} = \frac{0.1024 \times 144 \times 2000}{85.76 \times 520} = \mathbf{0.661\ lbm}$$

$P_a = P_{tot} - P_{v1} = 14.7 - 0.1024 = 14.598$ lbf/in.^{2}

$$m_a = \frac{P_a V}{R_a T} = \frac{14.598 \times 144 \times 2000}{53.34 \times 520} = 151.576 \text{ lbm}$$

$$w_1 = \frac{m_v}{m_a} = \frac{0.661}{151.576} = \mathbf{0.00436}$$

T_{dew} is T when $P_g(T_{dew}) = 0.1024$ lbf/in.^{2};   T = **35.5 F**

12.158E

A 1 lbm/s flow of saturated moist air (relative humidity 100%) at 14.7 psia and 50 F goes through a heat exchanger and comes out at 77 F. What is the exit relative humidity and the how much power is needed?

Solution:

State 1 : $\phi_1 = 1$; $P_v = P_g = 0.178$ psia

Eq.12.28: $w = 0.622\ P_v/P_a = 0.622 \times 0.178/(14.7 - 0.178) = 0.00762$

State 2 : No water added => $w_2 = w_1$ => $P_{v2} = P_{v1}$

$\phi_2 = P_{v2}/P_{g2} = 0.178/0.464 =$ **0.384 or 38 %**

Energy Eq.6.10

$$\dot{Q} = \dot{m}_2 h_2 - \dot{m}_1 h_1 = \dot{m}_a(h_2 - h_1)_{air} + w\dot{m}_a(h_2 - h_1)_{vapor}$$

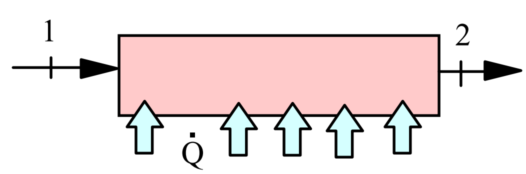
$$\dot{m}_{tot} = \dot{m}_a + \dot{m}_v = \dot{m}_a(1 + w_1)$$

Energy equation with $C_{P\ air}$ from F.4 and h's from F.7.1

$$\dot{Q} = \frac{\dot{m}_{tot}}{1 + w_1} C_{P\ air}\,(77 - 50) + \frac{\dot{m}_{tot}}{1 + w_1}\, w\,(h_{g2} - h_{g1})$$

$$= \frac{1}{1.00762} \times 0.24\,(77 - 50) + \frac{1 \times 0.00762}{1.00762}\,(1090.73 - 1083.29)$$

$= 6.431 + 0.0563 =$ **6.49 Btu/s**



12.159E

Consider a 10-ft^3 rigid tank containing an air-water vapor mixture at 14.7 lbf/in.^{2}, 90 F, with a 70% relative humidity. The system is cooled until the water just begins to condense. Determine the final temperature in the tank and the heat transfer for the process.

$P_{v1} = \phi P_{G1} = 0.7 \times 0.6988 = 0.489 \text{ lbf/in}^2$

Since m_v = const & V = const & also $P_v = P_{G2}$:

$P_{G2} = P_{v1} \times T_2/T_1 = 0.489 \times T_2/549.7$

For T_2 = 80 F: $0.489 \times 539.7/549.7 = 0.4801 \neq 0.5073$ (= P_G at 80 F)

For T_2 = 70 F: $0.489 \times 529.7/549.7 = 0.4712 \neq 0.3632$ (= P_G at 70 F)

interpolating → T_2 = **78.0 F**

$$w_2 = w_1 = 0.622 \frac{0.489}{(14.7-0.489)} = 0.0214$$

$$m_a = \frac{P_{a1}V}{R_aT_1} = \frac{14.211 \times 144 \times 10}{53.34 \times 549.7} = 0.698 \text{ lbm}$$

1st law:

$${}_1Q_2 = U_2 - U_1 = m_a(u_{a2} - u_{a1}) + m_v(u_{v2} - u_{v1})$$

$$= 0.698[0.171(78 - 90) + 0.0214(1036.3 - 1040.2)]$$

$$= 0.698(-2.135 \text{ Btu/lbm air}) = \mathbf{-1.49 \text{ Btu}}$$

12.160E

Consider a 35 ft^3/s flow of atmospheric air at 14.7 psia, 77 F and 80% relative humidity. Assume this flows into a basement room where it cools to 60 F at 14.7 psia. How much liquid will condense out?

Solution:

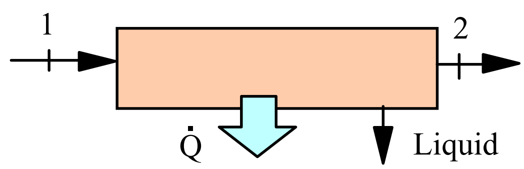
State 1: $P_g = P_{sat25} = 0.464$ psia => $P_v = \phi\, P_g = 0.8 \times 0.464 = 0.371$ psia

$$\dot{m}_{v1} = \frac{P_v\dot{V}}{R_vT} = \frac{0.371 \times 35 \times 144}{85.76 \times 536.67} = 0.0406 \text{ lbm/s}$$

$$w_1 = \frac{\dot{m}_{v1}}{\dot{m}_{A1}} = 0.622\,\frac{P_{v1}}{P_{A1}} = 0.622\,\frac{0.371}{14.7 - 0.371} = 0.0161$$

$$\dot{m}_{A1} = \frac{\dot{m}_{v1}}{w_1} = \frac{0.0406}{0.0161} = 2.522 \text{ lbm/s} = \dot{m}_{A2} \qquad \text{(continuity for air)}$$

Check for state 2:
$P_{g60F} = 0.256$ psia $<$ P_{v1}
so liquid water out.



State 2 is saturated $\phi_2 = 100\%$, $P_{v2} = P_{g2} = 0.256$ psia

$$w_2 = 0.622\,\frac{P_{v2}}{P_{A2}} = 0.622\,\frac{0.256}{14.7 - 0.256} = 0.0110$$

$$\dot{m}_{v2} = w_2\dot{m}_{A2} = 0.0110 \times 2.522 = 0.0277 \text{ lbm/s}$$

$$\dot{m}_{liq} = \dot{m}_{v1} - \dot{m}_{v2} = 0.0406 - 0.0277 = \mathbf{0.0129 \text{ lbm/s}}$$

Note that the given volume flow rate at the inlet is not that at the exit. The mass flow rate of dry air is the quantity that is the same at the inlet and exit.

12.161E

Air in a piston/cylinder is at 95 F, 15 lbf/in.^{2} and a relative humidity of 80%. It is now compressed to a pressure of 75 lbf/in.^{2} in a constant temperature process. Find the final relative and specific humidity and the volume ratio V_2/V_1.

Check if the second state is saturated or not. First assume no water is condensed

1: $P_{v1} = \phi_1 P_{G1} = 0.66$, $w_1 = 0.622 \times 0.66/14.34 = 0.0286$

2: $w_2 = 0.622\ P_{v2}/(P_2 - P_{v2}) = w_1$ => $P_{v2} = 3.297 > P_g = 0.825$ lbf/in^2

Conclusion is state 2 is saturated

$\boldsymbol{\phi_2 = 100\%}$, $w_2 = 0.622\ P_g/(P_2 - P_g) = \mathbf{0.00692}$

To get the volume ratio, write the ideal gas law for the vapor phases

$$V_2 = V_{a2} + V_{v2} + V_{f2} = (m_a R_a + m_{v2} R_v)T/P_2 + m_{liq}\, v_f$$

$$V_1 = V_{a1} + V_{v1} = (m_a R_a + m_{v1} R_v)T/P_1$$

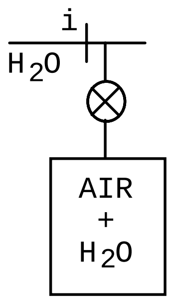
Take the ratio and devide through with $m_a R_a T/P_2$ to get

$$V_2/V_1 = (P_1/P_2)\,\frac{1 + 0.622 w_2 + (w_1 - w_2) P_2 v_f / R_a T}{1 + 0.622\, w_1} = \mathbf{0.1974}$$

The liquid contribution is nearly zero (= 0.000127) in the numerator.

12.162E

A 10-ft^3 rigid vessel initially contains moist air at 20 lbf/in.^{2}, 100 F, with a relative humidity of 10%. A supply line connected to this vessel by a valve carries steam at 100 lbf/in.^{2}, 400 F. The valve is opened, and steam flows into the vessel until the relative humidity of the resultant moist air mixture is 90%. Then the valve is closed. Sufficient heat is transferred from the vessel so the temperature remains at 100 F during the process. Determine the heat transfer for the process, the mass of steam entering the vessel, and the final pressure inside the vessel.



Air-vap mix: $P_1 = 20$ lbf/in^2, $T_1 = 560$ R

$\phi_1 = 0.10$, $T_2 = 560$ R, $\phi_2 = 0.90$

$P_{v1} = \phi_1 P_{G1} = 0.1\times0.9503 = 0.095$ lbf/in^2

$P_{v2} = 0.9\times0.9503 = 0.8553$ lbf/in^2

$P_{a2} = P_{a1} = P_1 - P_{v1} = 20 - 0.095 = 19.905$

$w_1 = 0.622\times0.095/19.905 = 0.002\,96$

$w_2 = 0.622\times0.8553/19.905 = 0.026\,64$

$$w = \frac{m_v}{m_a} \rightarrow m_{vi} = m_a(w_2-w_1), \quad m_a = \frac{19.905\times144\times10}{53.34\times560} = 0.96 \text{ lbm}$$

$P_2 = 19.905 + 0.855 = 20.76$ lbf/in^2

$m_{vi} = 0.96(0.02664 - 0.00296) = \mathbf{0.0227\ lbm}$

CV: vessel

$Q_{CV} = m_a(u_{a2}-u_{a1}) + m_{v2}u_{v2} - m_{v1}u_{v1} - m_{vi}h_i$

$u_v \approx u_{G\text{ at }T} \rightarrow \quad u_{v1} = u_{v2} = u_{G\text{ at }100\text{ F}}, \quad u_{a2} = u_{a1}$

$\rightarrow Q_{CV} = m_{vi}(u_{G\text{ at }T} - h_i) = 0.0227(1043.5\text{-}1227.5) = \mathbf{-4.18\ Btu}$

12.163E

A water-filled reactor of 50 ft^3 is at 2000 lbf/in.^{2}, 550 F and located inside an insulated containment room of 5000 ft^3 that has air at 1 atm. and 77 F. Due to a failure the reactor ruptures and the water fills the containment room. Find the final pressure.

CV Total container.

Energy: $m_v(u_2 - u_1) + m_a(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = 0$

Initial water: $v_1 = 0.021407$ ft^3/lbm, $u_1 = 539.24$, $m_v = V/v = 2335.7$ lbm

Initial air: $m_a = PV/RT = 14.7 \times 4950 \times 144/53.34 \times 536.67 = 366.04$ lbm

Substitute into energy equation

$$2335.7\ (u_2 - 539.24) + 366.04 \times 0.171\ (T_2 - 77) = 0$$

$$u_2 + 0.0268\ T_2 = 541.3 \qquad \& \qquad v_2 = V_2/m_v = 2.1407 \text{ ft}^3\text{/lbm}$$

Trial and error 2-phase (T_{guess}, v_2 => x_2 => u_2 => LHS)

$T = 300$ $x_2 = (2.1407 - 0.01745)/6.4537 = 0.329$, $u_2 = 542.73$ Btu/lbm

LHS = 550.789 Btu/lbm too large

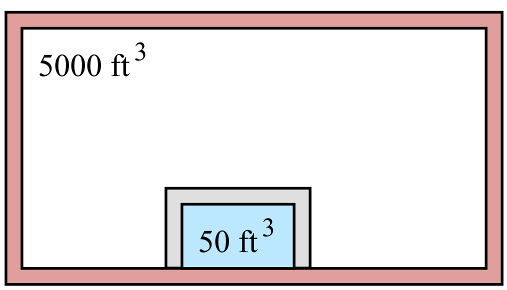
$T = 290$ $x_2 = (2.1407 - 0.01735)/7.4486 = 0.28507$, $u_2 = 498.27$ Btu/lbm

LHS = 506.05 Btu/lbm too small

$T_2 = 298$ F, $x_2 = 0.3198$, $P_{sat} = 65$ lbf/in^2, LHS = 541.5 OK

$$P_{a2} = P_{a1}V_1T_2/V_2T_1 = 14.7 \times 4950 \times 757.7/5000 \times 536.67 = 20.55 \text{ lbf/in}^2$$

=> $P_2 = P_{a2} + P_{sat} =$ **85.55 lbf/in^2**



12.164E

Two moist air streams with 85% relative humidity, both flowing at a rate of 0.2 lbm/s of dry air are mixed in a steady flow setup. One inlet flowstream is at 90 F and the other at 61 F. Find the exit relative humidity.

Solution:

CV mixing chamber.

Continuity Eq. water: $\dot{m}_{air}\, w_1 + \dot{m}_{air}\, w_2 = 2\dot{m}_{air}\, w_{ex}$;

Energy Eq.: $\dot{m}_{air}\, \tilde{h}_1 + \dot{m}_{air}\, \tilde{h}_2 = 2\dot{m}_{air}\, \tilde{h}_{ex}$

Properties from the tables and formulas

$P_{g90} = 0.699$; $P_{v1} = 0.85 \times 0.699 = 0.594$ psia

$w_1 = 0.622 \times 0.594 / (14.7 - 0.594) = 0.0262$

$P_{g61} = 0.2667$; $P_{v2} = 0.85 \times 0.2667 = 0.2267$ psia

$w_2 = 0.622 \times 0.2267 / (14.7 - 0.2267) = 0.00974$

Continuity Eq. water: $w_{ex} = (w_1 + w_2)/2 = 0.018$;

For the energy equation we have $\tilde{h} = h_a + wh_v$ so:

$$2\,\tilde{h}_{ex} - \tilde{h}_1 - \tilde{h}_2 = 0 = 2h_{a\ ex} - h_{a\ 1} - h_{a\ 2} + 2w_{ex}h_{v\ ex} - w_1 h_{v\ 1} - wh_{v\ 2}$$

we will use constant heat capacity to avoid an iteration on T_{ex}.

$$C_{p\ air}(2T_{ex} - T_1 - T_2) + C_{p\ H2O}(2w_{ex}T_{ex} - w_1T_1 - w_2T_2) = 0$$

$$T_{ex} = [\ C_{p\ air}(T_1 + T_2) + C_{p\ H2O}(w_1T_1 + w_2T_2)\ ]/\ [2C_{p\ air} + 2w_{ex}C_{p\ H2O}]$$

$$= [\ 0.24\ (90 + 61) + 0.447(0.0262 \times 90 + 0.00974 \times 61]/0.4961$$

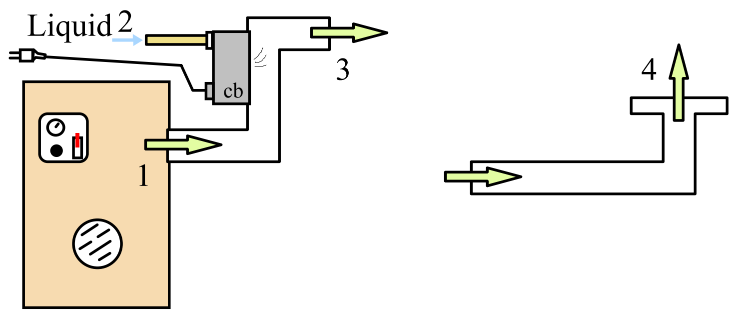
$$= 75.7\ \text{F}$$

$$P_{v\ ex} = \frac{w_{ex}}{0.622 + w_{ex}} P_{tot} = \frac{0.018}{0.622 + 0.018} 14.7 = 0.413 \text{ psia,}$$

$P_{g\ ex} = 0.445$ psia => $\phi = 0.413 / 0.445 =$ **0.93 or 93%**

12.165E

A flow of moist air from a domestic furnace, state 1 in Figure P12.98, is at 120 F, 10% relative humidity with a flow rate of 0.1 lbm/s dry air. A small electric heater adds steam at 212 F, 14.7 psia generated from tap water at 60 F. Up in the living room the flow comes out at state 4: 90 F, 60% relative humidity. Find the power needed for the electric heater and the heat transfer to the flow from state 1 to state 4.



State 1: F.7.1: $P_{g1} = 1.695$ psia, $h_{g1} = 1113.54$ Btu/lbm

$$P_{v1} = \phi P_{g1} = 0.1 \times 1.695 = 0.1695 \text{ psia}$$

$$w_1 = 0.622 \frac{P_{v1}}{P_{tot} - P_{v1}} = 0.622 \frac{0.1695}{14.7 - 0.1695} = 0.00726$$

Starte 2: $h_f = 28.08$ Btu/lbm ; State 2a: $h_{g\,212} = 1150.49$ Btu/lbm

State 4: $P_{g4} = 0.699$ psia, $h_{g4} = 1100.72$ Btu/lbm

$$P_{v4} = \phi P_{g4} = 0.6 \times 0.699 = 0.4194 \text{ psia}$$

$$w_4 = 0.622 \frac{P_{v4}}{P_{tot} - P_{v4}} = 0.622 \frac{0.4194}{14.7 - 0.4194} = 0.0183$$

$$\dot{m}_{liq} = \dot{m}_a (\omega_1 - \omega_4) = 0.1\,(0.0183 - 0.00726) = 0.0011 \text{ lbm/s}$$

Energy Eq. for heater:

$$\dot{Q}_{heater} = \dot{m}_{liq} (h_{out} - h_{in}) = 0.0011\,(1150.49 - 28.08)$$

$$= \mathbf{1.235\ Btu/s = 1.17\ kW}$$

Energy Eq. for line (excluding the heater):

$$\dot{Q}_{line} = \dot{m}_a (h_{a4} + w_4 h_{g4} - h_{a1} - w_1 h_{g1}) - \dot{m}_{liq}\, h_{g\,212}$$

$$= 0.1[\,0.24(90 - 120) + 0.0183 \times 1100.72 - 0.00726 \times 1113.54\,]$$

$$- 0.0011 \times 1150.49$$

$$= \mathbf{-0.78\ Btu/s}$$

12.166E

Atmospheric air at 95 F, relative humidity of 10%, is too warm and also too dry. An air conditioner should deliver air at 70 F and 50% relative humidity in the amount of 3600 ft^3 per hour. Sketch a setup to accomplish this, find any amount of liquid (at 68 F) that is needed or discarded and any heat transfer.

CV air conditioner. Check first the two states, inlet 1, exit 2.

In: $P_{g1} = 0.8246$ psia, $h_{g1} = 1102.9$ Btu/lbm, $h_{f,68} = 36.08$ Btu/lbm,

$P_{v1} = \phi_1 P_{g1} = 0.08246$ psia, $w_1 = 0.622 P_{v1}/(P_{tot}-P_{v1}) = 0.0035$

Ex: $P_{g2} = 0.36324$ psia, $h_{g2} = 1092$ Btu/lbm

$P_{v2} = \phi_2 P_{g2} = 0.1816$ psia, $w_2 = 0.622 P_{v2}/(P_{tot}-P_{v2}) = 0.00778$

Water must be added ($w_2 > w_1$). Continuity and energy equations

$$\dot{m}_A(1 + w_1) + \dot{m}_{liq} = \dot{m}_A(1 + w_2) \quad \& \quad \dot{m}_A h_{1mix} + \dot{m}_{liq} h_f + \dot{Q}_{CV} = \dot{m}_A h_{2mix}$$

$$\dot{m}_{tot} = P\dot{V}_{tot}/RT = 14.7\times3600\times144/53.34\times529.67 = 270 \text{ lbm/h}$$

$$\dot{m}_A = \dot{m}_{tot}/(1 + w_2) = 267.91 \text{ lbm/h}$$

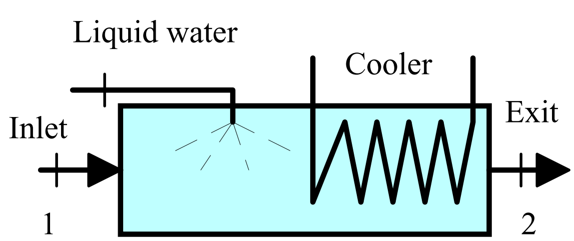
$$\dot{m}_{liq} = \dot{m}_A(w_2 - w_1) = 267.91(0.00778 - 0.0035) = \mathbf{1.147\ lbm/h}$$

$$\dot{Q}_{CV} = \dot{m}_A[C_{p\,a}(T_2 - T_1) + w_2 h_{g2} - w_1 h_{g1}] - \dot{m}_{liq} h_{f,68}$$

$$= 267.91\ [\ 0.24(70 - 95) + 0.00778 \times 1092 - 0.0035 \times 1102.9]$$

$$- 1.147 \times 36.08$$

$$= \mathbf{- 406.8\ Btu/h}$$



12.167E

An indoor pool evaporates 3 lbm/h of water, which is removed by a dehumidifier to maintain 70 F, Φ = 70% in the room. The dehumidifier is a refrigeration cycle in which air flowing over the evaporator cools such that liquid water drops out, and the air continues flowing over the condenser, as shown in Fig. P12.71. For an air flow rate of 0.2 lbm/s the unit requires 1.2 Btu/s input to a motor driving a fan and the compressor and it has a coefficient of performance, $\beta = Q_L/W_C = 2.0$. Find the state of the air after the evaporator, T_2, ω_2, Φ_2 and the heat rejected. Find the state of the air as it returns to the room and the compressor work input.

The unit must remove 3 lbm/h liquid to keep steady state in the room. As water condenses out state 2 is saturated.

1: 70 F, 70% => P_{g1} = 0.363 psia, h_{g1} = 1092.0 Btu/lbm,

$P_{v1} = \phi_1 P_{g1}$ = 0.2541 psia, $w_1 = 0.622\, P_{v1}/(P_{tot}-P_{v1}) = 0.01094$

CV 1 to 2: $\dot{m}_{liq} = \dot{m}_a(w_1 - w_2)$ => $w_2 = w_1 - \dot{m}_{liq}/\dot{m}_a$

$q_L = h_1 - h_2 - (w_1 - w_2)\, h_{f2}$

$w_2 = 0.01094 - 3/(3600 \times 0.2) = \mathbf{0.006774}$

$$P_{v2} = P_{g2} = P_{tot}\, w_2/(0.622 + w_2) = \frac{14.7 \times 0.006774}{0.628774} = 0.1584 \text{ psia}$$

Table F.7.1: T_2 = **46.8 F** h_{f2} = 14.88 btu/lbm, h_{g2} = 1081.905 Btu/lbm

$q_L = 0.24(70 - 46.8) + 0.01094 \times 1092 - 0.006774 \times 1081.905$

$- 0.00417 \times 14.88 = 10.12$ Btu/lbm dry air

$\dot{W}_c = \dot{m}_a\, q_L/\beta = \mathbf{1\ Btu/s}$

CV Total system :

$\tilde{h}_3 - \tilde{h}_1 = \dot{W}_{el}/\dot{m}_a - (w_1 - w_2)\, h_f = 1.2/0.2 - 0.062 = 5.938$ Btu/lbm dry air

$= C_{p\,a}(T_3 - T_1) + w_2 h_{v3} - w_1 h_{v1}$

Trial and error on T_3

3: $w_3 = w_2$, h_3 => T_3 = **112 F,** P_{g3} = 1.36 psia, $P_{v3} = P_{v2}$ = 0.1584

$\phi_3 = P_{v3}/P_{g3} = 0.12$ or ϕ_3 = **12%**

12.168E

To refresh air in a room, a counterflow heat exchanger is mounted in the wall, as shown in Fig. P12.115. It draws in outside air at 33 F, 80% relative humidity and draws room air, 104 F, 50% relative humidity, out. Assume an exchange of 6 lbm/min dry air in a steady flow device, and also that the room air exits the heat exchanger to the atmosphere at 72 F. Find the net amount of water removed from room, any liquid flow in the heat exchanger and (T, ϕ) for the fresh air entering the room.

State 3: P_{g3} = 1.0804 psia, h_{g3} = 1106.73 Btu/lbm,

$P_{v3} = \phi_3 P_{g3} = 0.5402$, $w_3 = 0.622\, P_{v3}/(P_{tot}-P_{v3}) = 0.02373$

The room air is cooled to 72 F $< T_{dew1}$ = 82 F so liquid will form in the exit flow channel and state 4 is saturated.

4: 72 F, ϕ = 100% => P_{g4} = 0.3918 psia, h_{g4} = 1092.91 Btu/lbm,

$w_4 = 0.017$, h_{f4} = 40.09 Btu/lbm

1: 33 F, ϕ = 80% => P_{g1} = 0.0925 psia, h_{g1} = 1075.83 Btu/lbm,

$P_{v1} = \phi_1 P_{g1}$ = 0.074 psia, $w_1 = 0.00315$

CV 3 to 4: $\dot{m}_{liq,4} = \dot{m}_a (w_3 - w_4) = 6\,(0.02373 - 0.017) = \mathbf{0.04\ lbm/min}$

CV room: $\dot{m}_{v,out} = \dot{m}_a (w_3 - w_2) = \dot{m}_a (w_3 - w_1)$

$= 6(0.02373 - 0.00315) = \mathbf{0.1235\ lbm/min}$

CV Heat exchanger: $\dot{m}_a(\tilde{h}_2 - \tilde{h}_1) = \dot{m}_a(\tilde{h}_3 - \tilde{h}_4) - \dot{m}_{liq} h_{f4}$

$C_{p\,a}(T_2 - T_1) + w_2 h_{v2} - w_1 h_{v1} = C_{p\,a}(T_3 - T_4) + w_3 h_{v3} - w_4 h_{v4} - (w_3 - w_4)\, h_{f4}$

$0.24(T_2 - 33) + w_2 h_{v2} - 3.3888 = 0.24(104-72) + 26.2627 - 18.5795 - 0.2698$

$0.24\, T_2 + 0.00315\, h_{v2} = 26.402$ btu/lbm

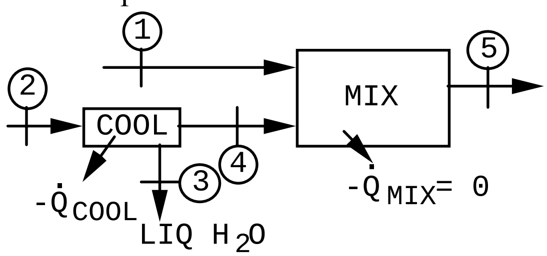
Trial and error on T_2: T_2 = **95.5 F**, P_{g2} = 0.837 psia, $P_{v2} = P_{v1}$

$\phi = P_{v2} / P_{g2} = 0.074 / 0.837 = 0.088$ or ϕ = **9%**

Review Problems

12.169E

Ambient air is at a condition of 14.7 lbf/in.^{2}, 95 F, 50% relative humidity. A steady stream of air at 14.7 lbf/in.^{2}, 73 F, 70% relative humidity, is to be produced by first cooling one stream to an appropriate temperature to condense out the proper amount of water and then mix this stream adiabatically with the second one at ambient conditions. What is the ratio of the two flow rates? To what temperature must the first stream be cooled?



$P_1 = P_2 = P_5 = 14.7$ lbf/in^2

$T_1 = T_2 = 95$ F

$\phi_1 = \phi_2 = 0.50, \;\; \phi_4 = 1.0$

$T_5 = 73$ F, $\phi_5 = 0.70$

$$P_{v1} = P_{v2} = 0.5\times0.8246 = 0.4123, \;\; w_1 = w_2 = 0.622\times\frac{0.4123}{14.7-0.4123} = 0.0179$$

$$P_{v5} = 0.7\times0.4064 = 0.2845 \quad => \quad w_5 = 0.622\times\frac{0.2845}{14.7-0.2845} = 0.0123$$

MIX: Call the mass flow ratio $r = m_{a2}/m_{a1}$

Conservation of water mass: $w_1 + r\,w_4 = (1 + r)w_5$

Energy Eq.: $h_{a1} + w_1h_{v1} + rh_{a4} + rw_4h_{v4} = (1 + r)h_{a5} + (1 + r)w_5h_{v5}$

$$\rightarrow \quad 0.0179 + rw_4 = (1 + r)\,0.0123$$

$$\text{or} \quad r = \frac{0.0179-0.0123}{0.0123-w_4}, \text{ with} \quad w_4 = 0.622 \times \frac{P_{G4}}{14.7-P_{G4}}$$

$$0.24\times555 + 0.0179 \times 1107.2 + r \times 0.24 \times T_4 + rw_4h_{v4}$$

$$= (1 + r) \times 0.24 \times 533 \; + (1 + r) \times 0.0123 \times 1093.3$$

$$\text{or} \quad r\Big[0.24 \times T_4 + w_4h_{G4} - 141.4\Big] + 11.66 = 0$$

Assume $T_4 = 40$ F $\rightarrow P_{G4} = 0.121\,66$ psia, $h_{G4} = 1078.9$ Btu/lbm

$$w_4 = 0.622 \times \frac{0.121\,66}{14.7-0.121\,66} = 0.0052$$

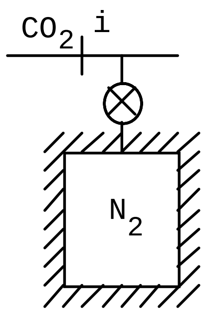
$$\frac{m_{a2}}{m_{a1}} = \frac{0.0179-0.0123}{0.0123-0.0052} = \mathbf{0.7887}$$

$$0.7887[0.24\times500 + 0.0052\times1078.9 - 141.4] + 11.66 = -0.29 \approx 0 \quad \text{OK}$$

$$=> \quad T_4 = \mathbf{40\ F}$$

12.170E

A 4-ft^3 insulated tank contains nitrogen gas at 30 lbf/in.^{2} and ambient temperature 77 F. The tank is connected by a valve to a supply line flowing carbon dioxide at 180 lbf/in.^{2}, 190 F. A mixture of 50 mole percent nitrogen and 50 mole percent carbon dioxide is to be obtained by opening the valve and allowing flow into the tank until an appropriate pressure is reached and the valve is closed. What is the pressure? The tank eventually cools to ambient temperature. Calculate the net entropy change for the overall process.



$V = 4\ \text{ft}^3$, $P_1 = 30\ \text{lbf/in}^2$, $T_1 = T_0 = 77$ F

At state 2: $y_{N_2} = y_{CO_2} = 0.50$

$n_{2\,CO_2} = n_{2\,N_2} = n_{1\,N_2} = P_1V/\bar{R}T_1$

$= 30\times4\times144/(1545\times536.67) = 0.02084$ lbmol

$n_2 = 0.04168$ lbmol

Energy Eq.: $n_i\bar{h}_i = n_2\bar{u}_2 - n_1\bar{u}_1$, use constant specific heats

$n_i\bar{C}_{Poi}T_i = (n_i\bar{C}_{Voi} + n_1\bar{C}_{Vo1})T_2 - n_1\bar{C}_{Vo1}T_1$

But $n_i = n_1$ $\rightarrow \bar{C}_{Poi}T_i = \bar{C}_{Voi}T_2 + \bar{C}_{Vo1}(T_2 - T_1)$

$44.01\times0.201\times 649.67 = 44.01 \times 0.156\ T_2 + 28.013 \times 0.178\ (T_2 - 536.67)$

$T_2 = 710.9$ R

$P_2 = n_2\bar{R}T_2/V = 0.04168\times1545\times710.9/4\times144 = 79.48\ \text{lbf/in}^2$

Cool to $T_3 = T_0 = 77\ \text{F} = 536.67$ R

$P_3 = P_2\times T_3/T_2 = 79.48\times 536.67/710.9 = 60\ \text{lbf/in}^2$

$Q_{23} = n_2\bar{C}_{Vo2}(T_3 - T_2) = 0.04168\ (0.5\times28.013\times0.178$

$+ 0.5\times44.01\times0.156)(536.67 - 710.9) = -43.0$ Btu

$\Delta S_{NET} = n_3\bar{s}_3 - n_1\bar{s}_1 - n_i\bar{s}_i - Q_{23}/T_0 = n_i[(\bar{s}_{CO_2})_3 - \bar{s}_i] + n_1[(\bar{s}_{N_2})_3 - \bar{s}_1] - Q_{23}/T_0$

$$= 0.02084(44.01\times0.201 \ln\frac{536.67}{649.67} - 1.98589 \ln\frac{0.5\times60}{180})$$

$$+ 0.02084\times(- 1.98589 \ln\frac{0.5\times60}{30}) - \frac{-43.0}{536.67}$$

$= +0.03893 + 0 + 0.0801 =$ **+0.119 Btu/R**