Quiz 3
Chemical Engineering Thermodynamics
February 5, 2015

1)

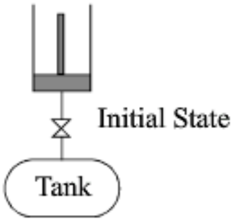
2.16 An adiabatic turbine expands steam from 500°C and 3.5 MPa to 200°C and 0.3 MPa. If the turbine generates 750 kW, what is the flow rate of steam through the turbine?

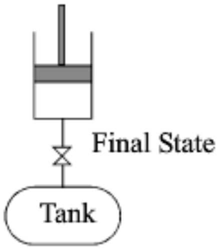
2) R = 8.314 J/(mole °K)

3.11 A well-insulated tank contains 1 mole of air at 2 MPa and 673 K. It is connected via a closed valve to an insulated piston/cylinder device that is initially empty. The piston may be assumed to be frictionless. The volumes of the piping and valve are negligible. The weight of the piston and atmospheric pressure are such that the total downward force can be balanced with gas pressure in the cylinder of 0.7 MPa. The valve between the tank and piston/cylinder is cracked open until the pressure is uniform throughout. The temperature in the tank is found to be 499.6 K. Air can be assumed to be an ideal gas with a temperature-independent heat capacity $C_P = 29.3$ J/mol-K.

(a) What is the number of moles left in the tank at the end of the process?

(b) Write and simplify the energy balance for the process. Determine the final temperature of the piston/cylinder gas.





3).

3.4 A distillation column with a total condenser is shown in Fig. 3.3. The system to be studied in this problem has an average enthalpy of vaporization of 32 kJ/mol, an average C_P^L of 146 J/mol°-C, and an average C_P^V of 93 J/mol°-C. Variable names for the various stream flow rates and the heat flow rates are given in the diagram. The feed can be liquid, vapor, or a mixture represented using subscripts to indicate the vapor and liquid flows, $F = F_V + F_L$. The enthalpy flow due to feed can be represented as: for saturated liquid, $F_L H^{satL}$; for saturated vapor, $F_V H^{satV}$; for subcooled liquid, $F_L H^{satL} + F_L C_P{}^L (T_F - T^{satL})$; for superheated vapor, $F_V H^{satV} + F_V C_P{}^V (T_F - T^{satV})$; and for a mix of vapor and liquid, $F_L H^{satL} + F_V H^{satV}$.

(a) Use a mass balance to show $F_V + V_S - V_R = L_S - L_R - F_L$.

[For parts (b)–(f), use the feed section mass and energy balances to show the desired result.]

(b) For saturated vapor feed, $F_L = 0$. Show $V_R = V_S + F_V$, $L_S = L_R$.

(c) For saturated liquid feed, $F_V = 0$. Show $V_S = V_R$, $L_S = L_R + F_L$.

(g) Use the mass and energy balances around the total condenser to relate the condenser duty to the enthalpy of vaporization, for the case of streams L_R and D being saturated liquid.

(h) Use the mass and energy balances around the reboiler to relate the reboiler duty to the enthalpy of vaporization.

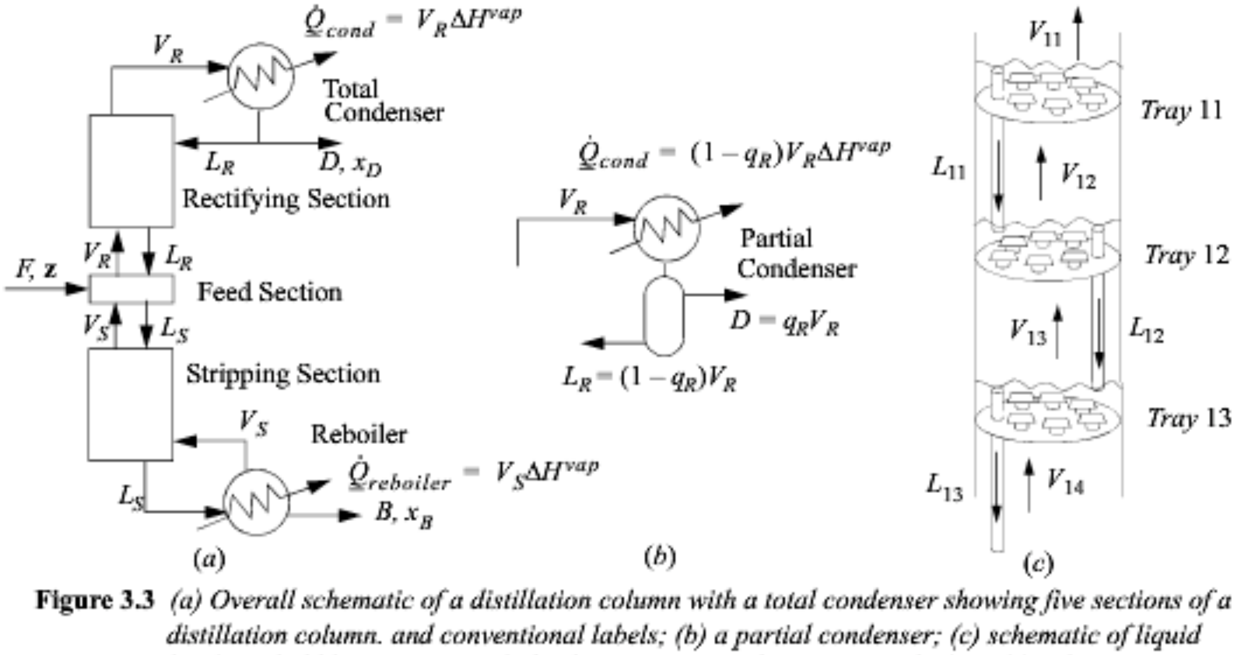


Figure 3.3 *(a) Overall schematic of a distillation column with a total condenser showing five sections of a distillation column. and conventional labels; (b) a partial condenser; (c) schematic of liquid levels on bubble cap trays with the downcomers used to maintain the liquid levels.*

$P = 0.20$MPa (120.3)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
120.3	0.8857	2529.1	2706.2	7.1269
150	0.9599	2577.1	2769.1	7.2810
200	1.0805	2654.6	2870.7	7.5081
250	1.1989	2731.4	2971.2	7.7100
300	1.3162	2808.8	3072.1	7.8941
350	1.4330	2887.3	3173.9	8.0644
400	1.5493	2967.1	3277.0	8.2236
450	1.6655	3048.5	3381.6	8.3734
500	1.7814	3131.4	3487.7	8.5152
550	1.8973	3215.9	3595.4	8.6502
600	2.0130	3302.2	3704.8	8.7792
650	2.1287	3390.2	3815.9	8.9030
700	2.2443	3479.9	3928.8	9.0220
750	2.3599	3571.4	4043.4	9.1369
800	2.4755	3664.7	4159.8	9.2479
850	2.5910	3759.6	4277.8	9.3555
900	2.7066	3856.3	4397.6	9.4598
950	2.8221	3954.7	4519.1	9.5612
1000	2.9375	4054.8	4642.3	9.6599
1050	3.0530	4156.4	4767.0	9.7560
1100	3.1685	4259.6	4893.3	9.8497
1150	3.2839	4364.3	5021.1	9.9411
1200	3.3994	4470.5	5150.4	10.0304
1250	3.5148	4578.1	5281.1	10.1176
1300	3.6302	4687.0	5413.1	10.2029

$P = 0.30$MPa (133.5)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
133.5	0.6058	2543.2	2724.9	6.9916
150	0.6340	2571.0	2761.2	7.0791
200	0.7164	2651.0	2865.9	7.3131
250	0.7964	2728.9	2967.9	7.5180
300	0.8753	2807.0	3069.6	7.7037
350	0.9536	2885.9	3172.0	7.8750
400	1.0315	2966.0	3275.5	8.0347
450	1.1092	3047.5	3380.3	8.1849
500	1.1867	3130.6	3486.6	8.3271
550	1.2641	3215.3	3594.5	8.4623
600	1.3414	3301.6	3704.0	8.5914
650	1.4186	3389.7	3815.3	8.7153
700	1.4958	3479.5	3928.2	8.8344
750	1.5729	3571.0	4042.9	8.9494
800	1.6500	3664.3	4159.3	9.0604
850	1.7271	3759.3	4277.4	9.1680
900	1.8042	3856.0	4397.3	9.2724
950	1.8812	3954.4	4518.8	9.3739
1000	1.9582	4054.5	4642.0	9.4726
1050	2.0352	4156.2	4766.7	9.5687
1100	2.1122	4259.4	4893.1	9.6624
1150	2.1892	4364.1	5020.9	9.7538
1200	2.2662	4470.3	5150.2	9.8431
1250	2.3432	4577.9	5280.9	9.9303
1300	2.4202	4686.9	5412.9	10.0156

$P = 0.40$MPa (143.6)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
143.6	0.4624	2553.1	2738.1	6.8955
150	0.4709	2564.4	2752.8	6.9306
200	0.5343	2647.2	2860.9	7.1723
250	0.5952	2726.4	2964.5	7.3804
300	0.6549	2805.1	3067.1	7.5677
350	0.7140	2884.4	3170.0	7.7399
400	0.7726	2964.9	3273.9	7.9002
450	0.8311	3046.6	3379.0	8.0508
500	0.8894	3129.8	3485.5	8.1933
550	0.9475	3214.6	3593.6	8.3287
600	1.0056	3301.0	3703.2	8.4580
650	1.0636	3389.1	3814.6	8.5820
700	1.1215	3479.0	3927.6	8.7012
750	1.1794	3570.6	4042.4	8.8162
800	1.2373	3663.9	4158.8	8.9273
850	1.2951	3759.0	4277.0	9.0350
900	1.3530	3855.7	4396.9	9.1394
950	1.4108	3954.2	4518.5	9.2409
1000	1.4686	4054.3	4641.7	9.3396
1050	1.5264	4155.9	4766.5	9.4357
1100	1.5841	4259.2	4892.8	9.5295
1150	1.6419	4363.9	5020.7	9.6209
1200	1.6997	4470.1	5150.0	9.7102
1250	1.7574	4577.8	5280.7	9.7975
1300	1.8152	4686.7	5412.8	9.8828

$P = 0.50$MPa (151.8)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
151.8	0.3748	2560.7	2748.1	6.8207
200	0.4250	2643.3	2855.8	7.0610
250	0.4744	2723.8	2961.0	7.2724
300	0.5226	2803.2	3064.6	7.4614
350	0.5702	2883.0	3168.1	7.6346
400	0.6173	2963.7	3272.3	7.7955
450	0.6642	3045.6	3377.7	7.9465
500	0.7109	3129.0	3484.5	8.0892
550	0.7576	3213.9	3592.7	8.2249
600	0.8041	3300.4	3702.5	8.3543
650	0.8505	3388.6	3813.9	8.4784
700	0.8970	3478.5	3927.0	8.5977
750	0.9433	3570.2	4041.8	8.7128
800	0.9897	3663.6	4158.4	8.8240
850	1.0360	3758.6	4276.6	8.9317

$P = 0.60$MPa (158.8)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
158.8	0.3156	2566.8	2756.1	6.7593
200	0.3521	2639.3	2850.6	6.9683
250	0.3939	2721.2	2957.6	7.1832
300	0.4344	2801.4	3062.0	7.3740
350	0.4743	2881.6	3166.1	7.5481
400	0.5137	2962.5	3270.8	7.7097
450	0.5530	3044.7	3376.5	7.8611
500	0.5920	3128.2	3483.4	8.0041
550	0.6309	3213.2	3591.8	8.1399
600	0.6698	3299.8	3701.7	8.2695
650	0.7085	3388.1	3813.2	8.3937
700	0.7472	3478.1	3926.4	8.5131
750	0.7859	3569.8	4041.3	8.6283
800	0.8246	3663.2	4157.9	8.7395
850	0.8632	3758.3	4276.2	8.8472

$P = 0.80$MPa (170.4)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
170.4	0.2403	2576.0	2768.3	6.6616
200	0.2609	2631.0	2839.7	6.8176
250	0.2932	2715.9	2950.4	7.0401
300	0.3242	2797.5	3056.9	7.2345
350	0.3544	2878.6	3162.2	7.4106
400	0.3843	2960.2	3267.6	7.5734
450	0.4139	3042.8	3373.9	7.7257
500	0.4433	3126.6	3481.3	7.8692
550	0.4726	3211.9	3590.0	8.0054
600	0.5019	3298.7	3700.1	8.1354
650	0.5310	3387.1	3811.9	8.2598
700	0.5601	3477.2	3925.3	8.3794
750	0.5892	3569.0	4040.3	8.4947
800	0.6182	3662.4	4157.0	8.6061
850	0.6472	3757.6	4275.4	8.7139

600	0.2500	3293.9	3693.9	7.8100
650	0.2647	3382.9	3806.5	7.9354
700	0.2794	3473.5	3920.5	8.0557
750	0.2940	3565.7	4036.1	8.1716
800	0.3087	3659.5	4153.3	8.2834
850	0.3232	3755.0	4272.2	8.3916
900	0.3378	3852.1	4392.6	8.4965
950	0.3523	3950.9	4514.6	8.5984
1000	0.3669	4051.2	4638.2	8.6974
1050	0.3814	4153.1	4763.4	8.7938
1100	0.3959	4256.6	4890.0	8.8878
1150	0.4104	4361.5	5018.2	8.9794
1200	0.4249	4467.9	5147.7	9.0689
1250	0.4394	4575.7	5278.7	9.1563
1300	0.4538	4684.8	5410.9	9.2417

600	0.2220	3292.7	3692.3	7.7543
650	0.2351	3381.9	3805.1	7.8799
700	0.2482	3472.6	3919.4	8.0004
750	0.2613	3564.9	4035.1	8.1164
800	0.2743	3658.8	4152.4	8.2284
850	0.2872	3754.3	4271.3	8.3367
900	0.3002	3851.5	4391.9	8.4416
950	0.3131	3950.3	4514.0	8.5435
1000	0.3261	4050.7	4637.6	8.6426
1050	0.3390	4152.7	4762.8	8.7391
1100	0.3519	4256.2	4889.5	8.8331
1150	0.3648	4361.1	5017.7	8.9248
1200	0.3777	4467.5	5147.3	9.0143
1250	0.3905	4575.3	5278.3	9.1017
1300	0.4034	4684.5	5410.6	9.1872

600	0.1996	3291.5	3690.7	7.7043
650	0.2115	3380.8	3803.8	7.8302
700	0.2233	3471.6	3918.2	7.9509
750	0.2350	3564.0	4034.1	8.0670
800	0.2467	3658.0	4151.5	8.1790
850	0.2584	3753.6	4270.5	8.2874
900	0.2701	3850.9	4391.1	8.3925
950	0.2818	3949.8	4513.3	8.4945
1000	0.2934	4050.2	4637.0	8.5936
1050	0.3051	4152.2	4762.3	8.6901
1100	0.3167	4255.7	4889.1	8.7842
1150	0.3283	4360.7	5017.3	8.8759
1200	0.3399	4467.2	5147.0	8.9654
1250	0.3515	4575.0	5278.0	9.0529
1300	0.3631	4684.1	5410.3	9.1384

$P = 2.50$MPa (224.0)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
224.0	0.0799	2602.1	2801.9	6.2558
250	0.0871	2663.3	2880.9	6.4107
300	0.0989	2762.2	3009.6	6.6459
350	0.1098	2852.5	3127.0	6.8424
400	0.1201	2939.8	3240.1	7.0170
450	0.1302	3026.2	3351.6	7.1767
500	0.1400	3112.8	3462.7	7.3254
550	0.1497	3200.1	3574.3	7.4653
600	0.1593	3288.5	3686.8	7.5979
650	0.1689	3378.2	3800.4	7.7243
700	0.1783	3469.3	3915.2	7.8455
750	0.1878	3562.0	4031.5	7.9620
800	0.1972	3656.2	4149.2	8.0743
850	0.2066	3752.0	4268.5	8.1830
900	0.2160	3849.4	4389.3	8.2882
950	0.2253	3948.4	4511.7	8.3904
1000	0.2347	4048.9	4635.6	8.4896
1050	0.2440	4151.0	4761.0	8.5863
1100	0.2533	4254.7	4887.9	8.6804
1150	0.2626	4359.7	5016.2	8.7722
1200	0.2719	4466.2	5146.0	8.8618
1250	0.2812	4574.1	5277.1	8.9493
1300	0.2905	4683.3	5409.5	9.0349

$P = 3.00$MPa (233.9)

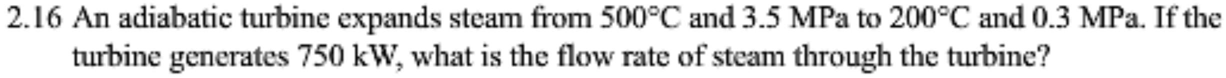
T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
233.9	0.0667	2603.2	2803.2	6.1856
250	0.0706	2644.7	2856.5	6.2893
300	0.0812	2750.8	2994.3	6.5412
350	0.0906	2844.4	3116.1	6.7449
400	0.0994	2933.5	3231.7	6.9234
450	0.1079	3021.2	3344.8	7.0856
500	0.1162	3108.6	3457.2	7.2359
550	0.1244	3196.6	3569.7	7.3768
600	0.1324	3285.5	3682.8	7.5103
650	0.1405	3375.6	3796.9	7.6373
700	0.1484	3467.0	3912.2	7.7590
750	0.1563	3559.9	4028.9	7.8758
800	0.1642	3654.3	4146.9	7.9885
850	0.1720	3750.3	4266.5	8.0973
900	0.1799	3847.9	4387.5	8.2028
950	0.1877	3947.0	4510.1	8.3051
1000	0.1955	4047.7	4634.1	8.4045
1050	0.2033	4149.9	4759.7	8.5012
1100	0.2111	4253.6	4886.7	8.5955
1150	0.2188	4358.7	5015.2	8.6874
1200	0.2266	4465.3	5145.0	8.7770
1250	0.2343	4573.3	5276.2	8.8646
1300	0.2421	4682.5	5408.8	8.9502

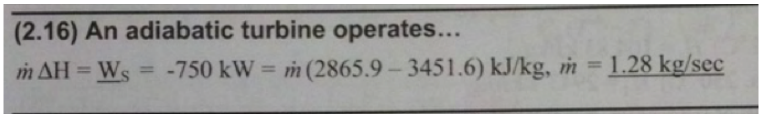
$P = 3.50$MPa (242.6)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
242.6	0.0571	2602.9	2802.6	6.1243
250	0.0588	2624.0	2829.7	6.1764
300	0.0685	2738.8	2978.4	6.4484
350	0.0768	2836.0	3104.8	6.6601
400	0.0846	2927.2	3223.2	6.8427
450	0.0920	3016.1	3338.0	7.0074
500	0.0992	3104.5	3451.6	7.1593
550	0.1063	3193.1	3565.0	7.3014
600	0.1133	3282.5	3678.9	7.4356
650	0.1202	3372.9	3793.5	7.5633
700	0.1270	3464.7	3909.3	7.6854
750	0.1338	3557.8	4026.3	7.8027
800	0.1406	3652.5	4144.6	7.9156
850	0.1474	3748.6	4264.4	8.0247
900	0.1541	3846.4	4385.7	8.1303
950	0.1608	3945.6	4508.4	8.2328
1000	0.1675	4046.4	4632.7	8.3324
1050	0.1742	4148.7	4758.4	8.4292
1100	0.1809	4252.5	4885.6	8.5235
1150	0.1875	4357.7	5014.1	8.6155
1200	0.1942	4464.4	5144.1	8.7053
1250	0.2009	4572.4	5275.4	8.7929
1300	0.2075	4681.7	5408.0	8.8785

Answers Quiz 3
Chemical Engineering Thermodynamics
February 5, 2015

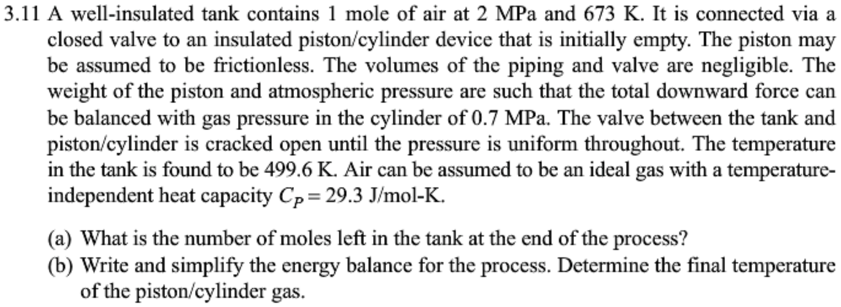
1)


2.16 An adiabatic turbine expands steam from 500°C and 3.5 MPa to 200°C and 0.3 MPa. If the turbine generates 750 kW, what is the flow rate of steam through the turbine?

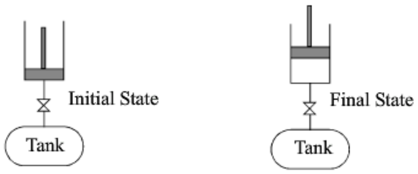

(2.16) An adiabatic turbine operates...

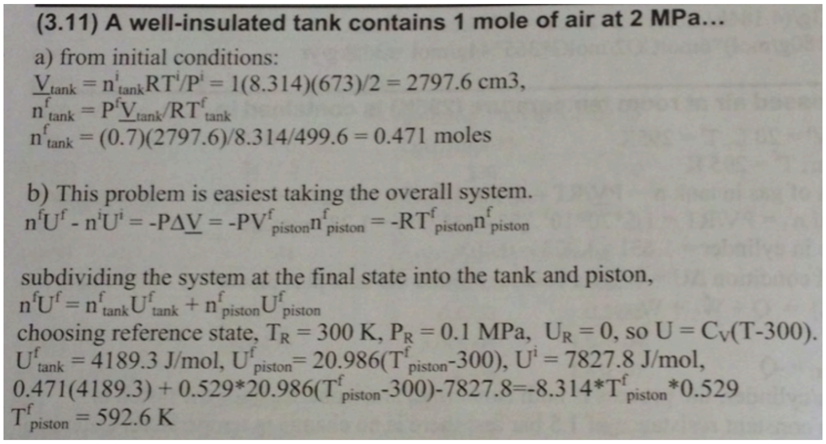
$\dot{m}\,\Delta H = \underline{W}_S = -750 \text{ kW} = \dot{m}\,(2865.9 - 3451.6) \text{ kJ/kg},\ \dot{m} = \underline{1.28 \text{ kg/sec}}$

2)


3.11 A well-insulated tank contains 1 mole of air at 2 MPa and 673 K. It is connected via a closed valve to an insulated piston/cylinder device that is initially empty. The piston may be assumed to be frictionless. The volumes of the piping and valve are negligible. The weight of the piston and atmospheric pressure are such that the total downward force can be balanced with gas pressure in the cylinder of 0.7 MPa. The valve between the tank and piston/cylinder is cracked open until the pressure is uniform throughout. The temperature in the tank is found to be 499.6 K. Air can be assumed to be an ideal gas with a temperature-independent heat capacity $C_P = 29.3$ J/mol-K.

(a) What is the number of moles left in the tank at the end of the process?
(b) Write and simplify the energy balance for the process. Determine the final temperature of the piston/cylinder gas.




(3.11) A well-insulated tank contains 1 mole of air at 2 MPa...

a) from initial conditions:

$\underline{V}_{tank} = n^i_{tank}RT^i/P^i = 1(8.314)(673)/2 = 2797.6$ cm3,

$n^f_{tank} = P^f\underline{V}_{tank}/RT^f_{tank}$

$n^f_{tank} = (0.7)(2797.6)/8.314/499.6 = 0.471$ moles

b) This problem is easiest taking the overall system.

$n^fU^f - n^iU^i = -P\Delta\underline{V} = -P\underline{V}^f_{piston}n^f_{piston} = -RT^f_{piston}n^f_{piston}$

subdividing the system at the final state into the tank and piston,

$n^fU^f = n^f_{tank}U^f_{tank} + n^f_{piston}U^f_{piston}$

choosing reference state, $T_R = 300$ K, $P_R = 0.1$ MPa, $U_R = 0$, so $U = C_V(T-300)$.

$U^f_{tank} = 4189.3$ J/mol, $U^f_{piston} = 20.986(T^f_{piston}-300)$, $U^i = 7827.8$ J/mol,

$0.471(4189.3) + 0.529*20.986(T^f_{piston}-300)-7827.8=-8.314*T^f_{piston}*0.529$

$T^f_{piston} = 592.6$ K

3)

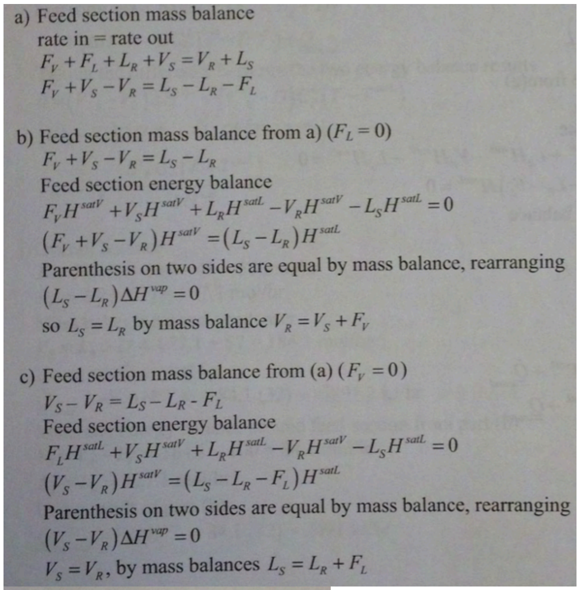
3.4 A distillation column with a total condenser is shown in Fig. 3.3. The system to be studied in this problem has an average enthalpy of vaporization of 32 kJ/mol, an average C_P^L of 146 J/mol°-C, and an average C_P^V of 93 J/mol°-C. Variable names for the various stream flow rates and the heat flow rates are given in the diagram. The feed can be liquid, vapor, or a mixture represented using subscripts to indicate the vapor and liquid flows, $F = F_V + F_L$. The enthalpy flow due to feed can be represented as: for saturated liquid, $F_L H^{satL}$; for saturated vapor, $F_V H^{satV}$; for subcooled liquid, $F_L H^{satL} + F_L C_P{}^L (T_F - T^{satL})$; for superheated vapor, $F_V H^{satV} + F_V C_P{}^V (T_F - T^{satV})$; and for a mix of vapor and liquid, $F_L H^{satL} + F_V H^{satV}$.

(a) Use a mass balance to show $F_V + V_S - V_R = L_S - L_R - F_L$.

[For parts (b)–(f), use the feed section mass and energy balances to show the desired result.]

(b) For saturated vapor feed, $F_L = 0$. Show $V_R = V_S + F_V$, $L_S = L_R$.
(c) For saturated liquid feed, $F_V = 0$. Show $V_S = V_R$, $L_S = L_R + F_L$.

(g) Use the mass and energy balances around the total condenser to relate the condenser duty to the enthalpy of vaporization, for the case of streams L_R and D being saturated liquid.
(h) Use the mass and energy balances around the reboiler to relate the reboiler duty to the enthalpy of vaporization.



a) Feed section mass balance

rate in = rate out

$F_V + F_L + L_R + V_S = V_R + L_S$

$F_V + V_S - V_R = L_S - L_R - F_L$

b) Feed section mass balance from a) ($F_L = 0$)

$F_V + V_S - V_R = L_S - L_R$

Feed section energy balance

$F_V H^{satV} + V_S H^{satV} + L_R H^{satL} - V_R H^{satV} - L_S H^{satL} = 0$

$(F_V + V_S - V_R) H^{satV} = (L_S - L_R) H^{satL}$

Parenthesis on two sides are equal by mass balance, rearranging

$(L_S - L_R)\Delta H^{vap} = 0$

so $L_S = L_R$ by mass balance $V_R = V_S + F_V$

c) Feed section mass balance from (a) ($F_V = 0$)

$V_S - V_R = L_S - L_R - F_L$

Feed section energy balance

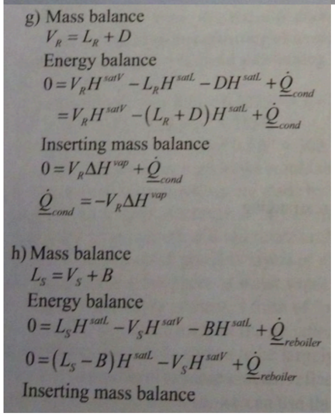
$F_L H^{satL} + V_S H^{satV} + L_R H^{satL} - V_R H^{satV} - L_S H^{satL} = 0$

$(V_S - V_R) H^{satV} = (L_S - L_R - F_L) H^{satL}$

Parenthesis on two sides are equal by mass balance, rearranging

$(V_S - V_R)\Delta H^{vap} = 0$

$V_S = V_R$, by mass balances $L_S = L_R + F_L$



g) Mass balance

$V_R = L_R + D$

Energy balance

$0 = V_R H^{satV} - L_R H^{satL} - D H^{satL} + \underline{\dot{Q}}_{cond}$

$= V_R H^{satV} - (L_R + D) H^{satL} + \underline{\dot{Q}}_{cond}$

Inserting mass balance

$0 = V_R \Delta H^{vap} + \underline{\dot{Q}}_{cond}$

$\underline{\dot{Q}}_{cond} = -V_R \Delta H^{vap}$

h) Mass balance

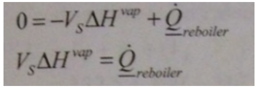
$L_S = V_S + B$

Energy balance

$0 = L_S H^{satL} - V_S H^{satV} - B H^{satL} + \underline{\dot{Q}}_{reboiler}$

$0 = (L_S - B) H^{satL} - V_S H^{satV} + \underline{\dot{Q}}_{reboiler}$

Inserting mass balance



$0 = -V_S \Delta H^{vap} + \underline{\dot{Q}}_{reboiler}$

$V_S \Delta H^{vap} = \underline{\dot{Q}}_{reboiler}$