Questions to practice properties of fluids calculations and table reading – Week 4

From Chapter 1.5 to 1.7

1. If the steam at 9 bar is further reduced to 1 bar by an isentropic process, what is the dryness fraction of the steam produced at the end of the process, and what is the temperature?
2. Use the spreadsheet produced in the consolidation session to a plot of temperature vs. specific entropy plot for saturated water and saturated steam with constant pressure lines for 10 bar and 160 bar. This should show the saturation line across the chart and the superheat behaviour for specific entropy.
3. Calculate the *kinematic* viscosity of water liquid and vapour at 75°C. What do you notice about the comparison of vapour and liquid when expressed in this way as opposed to dynamic viscosity? Hint: you need density via specific volume.
4. Interpolate the conductivity of dry air tables to find the conductivity at 88°C. Compare this with the conductivity of saturated steam at 88°C.
5. The atmospheric pressure at 4000 m elevation above sea level is found on p.24 of the tables. What is the saturation temperature at this height? You may need to interpolate on p.3 of the tables.

From Chapter 2.1 to 2.3a

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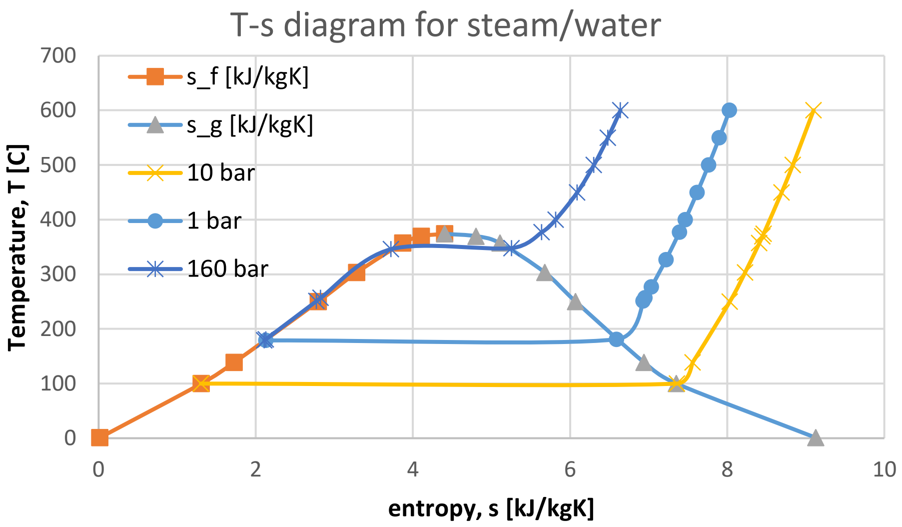
1. A mountaineer boils water on a 4,000m mountain top? What is the atmospheric temperature there? What temperature would a cup of tea be there?
2. What pressure is required in a freezer compartment evaporator coil using refrigerant R134a if the temperature is to be maintained at -20°C?
3. What are the enthalpy and entropy when the R134a is all liquid and then when it is all vapour? What does the change in entropy between the two states tell you?
4. Assuming a mass flow rate of R134a of 20g/s, and making use of the SFEE, what heat transfer rate occurs in the evaporator if the refrigerant leaves at saturated gas condition (i.e. just all vapour, with no superheat) and enters at saturated liquid condition (i.e. just all liquid and no sub-cooling)?

Answers to properties questions Week 4

From chapter 1.5 to 1.7

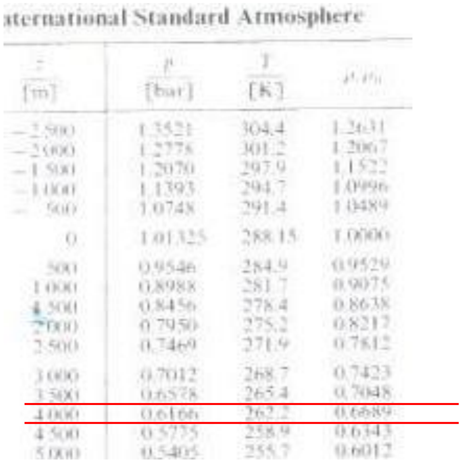
1. starting from the entropy of Q16, which is the same as Q14 (isentropic) and doing a further isentropic expansion to 1 bar, find the entropy point is below the saturation entropy (confirm p.6 left hand column shows s_g sat is 7.359 kJ/kgK) therefore go to p.4 and 1 bar condition and use the dryness fraction idea (x proportion of vapour and (1-x) proportion of liquid: $s = xs_g + (1-x)s_f \rightarrow 6.797 = x7.359 + (1-x)1.303$ and therefore x = 0.907, and the temperature is 99.6 °C (i.e. saturation temperature from column 2)
2. use the entropyW(T,p) function is the quickest way to do this, with T in K and p in bar produces the following chart:



3. On page 10 of the tables, or using the Excel spreadsheet, the dynamic viscosity is given at 75°C: $\mu_f = 374\times10^{-6}$ kg·m^{-1}·s^{-1} and $\mu_g = 11.1\times10^{-6}$ kg·m^{-1}·s^{-1}. But the kinematic viscosity is ν, with units m^{2}s^{-1}, indicating an area growth of the diffusion front of the fluid as time passes (imagine a sphere of the fluid spreading out and the perimeter gets bigger), and a small calculation is required. $\nu\times v$ where v is specific volume [m^3·kg^{-1}] produces units m^2·s^{-1}. Therefore on p.10 for liquid, $v_f = 0.1026\times10^{-2}$ m^{3}kg^{-1}, and from p.2 for steam $v_g = 4.133$ m^{3}kg^{-1}.
   Therefore $\nu_f = 374\times10^{-6} \times 0.1026\times10^{-2} = 3.8\times10^{-7}$ m^{2}s^{-1}, and
   $\nu_g = 11.1\times10^{-6} \times 4.133 = 4.588\times10^{-5}$ m^{2}s^{-1}.
4. Dry air data is found on p.16 of the Rogers and Mayhew tables. Thermal conductivty at 88°C is 361 K. We have on the tables 350 K and 375 K, the values of k there are 3.003×10^{-5} kWm^{-1}K^{-1}, and 3.186×10^{-5} kWm^{-1}K^{-1}. Therefore interpolate:
$$\frac{k-k1}{k2-k1} = \frac{T-T1}{T2-T1}$$
$$\frac{k-3.003}{3.186-3.003} = \frac{361-350}{375-350}$$
   which produces k = 3.084×10^{-5} kWm^{-1}K^{-1}, or 0.03084 Wm^{-1}K^{-1}.
5. the trick here is that the pressure at the height above sea level is given, it is 0.6166 bar; therefore the effect on boiling point will be seen on page 2 and 3 again, and it is seen to be between 86 and 88°C – could interpolate but this will do.

From chapter 2.1 to 2.3a

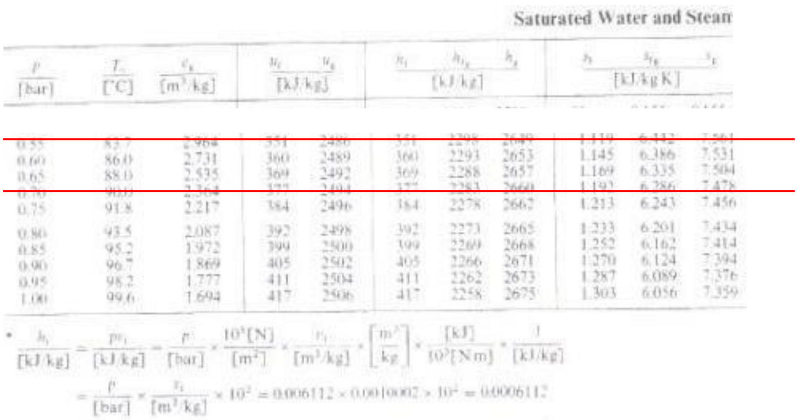
1. For the atmospheric temperature, you need the ‘International Standard Atmosphere’ table on p.24 of the tables. Looking at 4,000 m for z, the height above sea level, the corresponding temperature is 262.2K or -10.8°C.



International Standard Atmosphere

z [m]	p [bar]	T [K]	ρ/ρ_0
−2 500	1.3521	304.4	1.2631
−2 000	1.2778	301.2	1.2067
−1 500	1.2070	297.9	1.1522
−1 000	1.1393	294.7	1.0996
−500	1.0748	291.4	1.0489
0	1.01325	288.15	1.0000
500	0.9546	284.9	0.9529
1 000	0.8988	281.7	0.9075
1 500	0.8456	278.4	0.8638
2 000	0.7950	275.2	0.8217
2 500	0.7469	271.9	0.7812
3 000	0.7012	268.7	0.7423
3 500	0.6578	265.4	0.7048
4 000	0.6166	262.2	0.6689
4 500	0.5775	258.9	0.6343
5 000	0.5405	255.7	0.6012

Note the atmospheric pressure at this height is also indicated, as p in bar, as 0.6166 bar, or 61,666 Pa. This pressure determines the temperature that water boils at on the mountain top. When the temperature of the water has a saturation pressure corresponding to this, then the water will boil. So looking at the saturated Water and Steam table on p.3, we see that for 0.6166 bar, the saturation temperature, T_S is about 86°C – you could interpolate for a more accurate temperature if you wish.



Saturated Water and Steam

p [bar]	T_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
0.55	83.7	2.964	351	2486	351	2298	2649	1.119	6.442	7.561
0.60	86.0	2.731	360	2489	360	2293	2653	1.145	6.386	7.531
0.65	88.0	2.535	369	2492	369	2288	2657	1.169	6.335	7.504
0.70	90.0	2.364	377	2494	377	2283	2660	1.192	6.286	7.478
0.75	91.8	2.217	384	2496	384	2278	2662	1.213	6.243	7.456
0.80	93.5	2.087	392	2498	392	2273	2665	1.233	6.201	7.434
0.85	95.2	1.972	399	2500	399	2269	2668	1.252	6.162	7.414
0.90	96.7	1.869	405	2502	405	2266	2671	1.270	6.124	7.394
0.95	98.2	1.777	411	2504	411	2262	2673	1.287	6.089	7.376
1.00	99.6	1.694	417	2506	417	2258	2675	1.303	6.056	7.359

$$\frac{h_f}{[kJ/kg]} = \frac{pv_f}{[kJ/kg]} = \frac{p}{[bar]}\times\frac{10^5[N]}{[m^2]}\times\frac{v_f}{[m^3/kg]}\times\left[\frac{m^3}{kg}\right]\times\frac{[kJ]}{10^3[Nm]}\times\frac{1}{[kJ/kg]} = \frac{p}{[bar]}\times\frac{v_f}{[m^3/kg]}\times10^2 = 0.006112\times0.0010002\times10^2 = 0.0006112$$

2. The idea of the evaporator coil here is to maintain a boiling refrigerant inside the coil at the temperature required in the freezer compartment. Boiling occurs when the pressure of the refrigerant is the saturation pressure, at which boiling occurs at the saturation temperature. This information is presented in the tables on p.15 to be 1.3272 bar. Alternatively looking at the p-h diagram for R134a, the temperature line corresponding to -20°C passes through the vapour-liquid mixture region (under the domed curve) when the pressure is between 1.3 and 1.4 bar.

3. From the tables on p.15, the enthalpy of saturated liquid (i.e. when the entire sample of R134a is just liquid at the saturation temperature) is indicated by h_f [kJ/kg] and enthalpy of saturated vapour (when the sample is all just vapour at the saturation temperature) is h_g [kJ/kg]. At -20°C, from the tables h_f = 173.67 kJ/kg and h_g = 386.44 kJ/kg. Notice that if we used the p-h diagram instead, then h_f = 75 kJ/kg and h_g = 285 kJ/kg – the reason for the difference is the arbitrary selection of the zero for h, as stated at the

Tetrafluoroethane – $CH_2F–CF_3$ (Refrigerant 134a)

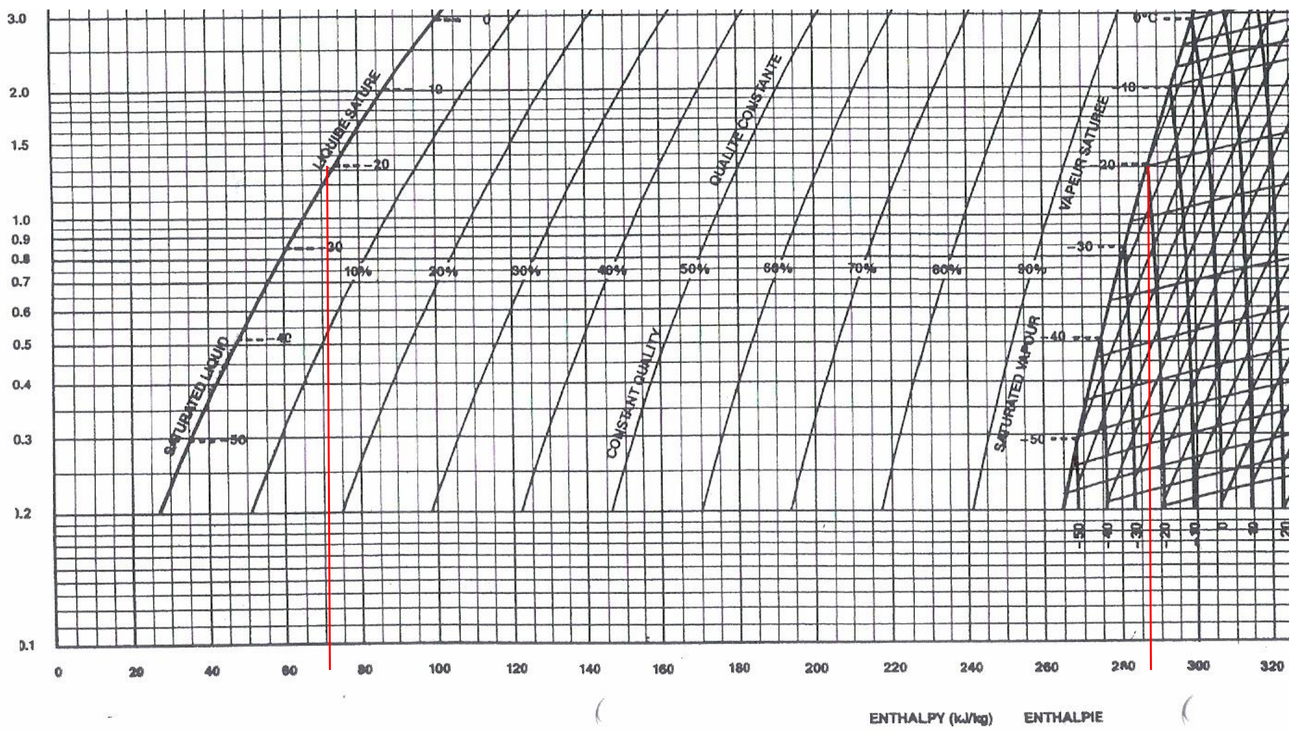
Saturation Values							Superheat $(T - T_s)$			
							10 K		20 K	
T_s [°C]	p_s [bar]	v_g [m³/kg]	h_f [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_g [kJ/kg K]	h [kJ/kg]	s [kJ/kg K]	h [kJ/kg]	s [kJ/kg K]
−30	0.8435	0.22577	160.89	380.27	0.8490	1.7512	388.12	1.7828	396.07	1.8137
−25	1.0637	0.18146	167.25	383.37	0.8748	1.7457	391.38	1.7774	399.49	1.8082
−20	1.3272	0.14725	173.67	386.44	0.9003	1.7408	394.63	1.7726	402.90	1.8034
−15	1.6393	0.12055	180.16	389.49	0.9256	1.7365	397.86	1.7683	406.29	1.7992
−10	2.0060	0.09949	186.71	392.51	0.9506	1.7327	401.07	1.7647	409.67	1.7956
−5	2.4335	0.08273	193.32	395.49	0.9754	1.7294	404.25	1.7614	413.02	1.7924
0†	2.9281	0.06925	200.00†	398.43	1.0000†	1.7264	407.40	1.7587	416.35	1.7897
5	3.4966	0.05834	206.75	401.33	1.0243	1.7238	410.50	1.7562	419.65	1.7874
10	4.1459	0.04942	213.57	404.16	1.0484	1.7215	413.56	1.7542	422.00	1.7855

Molar mass $\tilde{m}$ = 102.03 kg/kmol; further properties of the liquid are given on p. 23.

†The datum state for refrigerant properties used to be −40 °C (h_f = 0, s_f = 0), a temperature at which −40 °C = −40 °F. This datum state is used here for the R717 and R12 tables. Nowadays the datum state chosen is 0 °C (h_f = 200 kJ/kg, s_f = 1.000 kJ/kg K), a choice which ensures that no negative values of h_f and s_f appear in common refrigerant tables. This datum state is chosen for the R134a table.

It must be remembered that datum states are quite arbitrary and do not affect calculations which involve changes of properties, such as Δh.

bottom of the table. The difference in both cases can be easily verified to be the same, i.e. 386-174=212 kJ/kg and 285-75=210 kJ/kg. The change in entropy between the two states is, from the tables, s_f = 0.9003 kJ/kgK and s_g = 1.7408 kJ/kgK i.e. and increase of entropy from liquid to vapour of 0.84 kJ/kgK – there is more disorder in the vapour state.



4. The enthalpy change was as in question 3, 210 kJ/kg; given the mass flow rate there are 20 g per second flowing through the evaporator, and the enthalpy change rate in the evaporator is 0.02×210 = 4.2 kW.