Air conditioning revision examples. Week 7.

1. An air conditioning unit operating in air at 1 atm, has air entering the dehumidifier with absolute humidity 0.01. After the dehumidifier, the absolute humidity is 0.006. Calculate the vapour pressure at each of these two points.

2. In Q1 the flow rate of atmospheric air into the air conditioning unit is 0.5 kg/s. Calculate the mass flow rate of the dry air, and the mass flow rate of the water vapour in the air before and after the dehumidifier.

3. For the air conditioning system in Q1, use the tables to find the temperature after the dehumidifier.

4. For the air conditioning system in Q1, find the c_p of the dry air at the average of the pre- and post-dehumidifier temperatures, given the pre-dehumidifier temperature is 30°C.

5. For the air conditioning system in Q1 find from the tables the specific enthalpy of liquid water at the dew point temperature after the dehumidifier. Find also the specific enthalpy of the water vapour in the air before and after the dehumidifier.

6. For the air conditioning system in Q1, using the results of the questions Q1-Q5, calculate the heat transfer out of the dehumidifier.

Vapour power cycles revision examples

1. Calculate the Carnot efficiency for a power cycle using max temperature 2000K and min temperature 300K.

2. If 50 kg/s of coal is consumed in a power station using the temperatures of question 1, and the coal releases 30 MJ for every kg burned, what is the greatest possible work that can be extracted from the station?

3. What are the two main reasons why all of this work cannot be generated?

Air conditioning revision solutions Week 7

1. considering the entry to dehumidifier as point 2, and exit as point 3, and using:

$$\varpi = \frac{0.622p_S}{p-p_S} = \frac{0.622p_S}{1.01325-p_S} = 0.01 \Rightarrow p_{S2} \Rightarrow 0.01 \times 1.01325 - 0.01p_{S2} = 0.622p_{S2}$$

$$0.01013 = 0.632p_{S2} \Rightarrow p_{S2} = 0.016\,\text{bar}$$

p_{S3} must be 100% ϕ, $\therefore p_g = p_{SAT} = p_{S3}$

$$\varpi = \frac{0.622p_{S3}}{p-p_{S3}} \Rightarrow 0.006 = \frac{0.622p_{S3}}{1.01325-p_{S3}} \Rightarrow 0.00608 - 0.006p_{S3} = 0.622p_{S3}$$

$$\Rightarrow 0.00608 = 0.628p_{S3} \rightarrow p_{S3} = 0.0097\,\text{bar}$$

2. atmospheric air mass flow rate at entry is given as 0.5 kg/s. We know $\omega = \dfrac{\dot{m}_S}{\dot{m}_{dry-air}}$ and

$\dot{m}_{dry-air} + \dot{m}_S = 0.5\ kg \cdot s^{-1} \therefore \dot{m}_S = 0.005\ kg \cdot s^{-1}$ and $\dot{m}_{\text{DRYAIR}} = 0.495$ kg/s.

At exit $\dot{m}_{\text{DRYAIR}} = 0.495$ kg/s still – it can only go out one way. We know that ω = 0.006,

and therefore we say $\omega = \dfrac{\dot{m}_S}{0.495} - 0.006 \rightarrow \dot{m}_S = 0.003\ kg \cdot s^{-1}$.

3. at p_{S3}, t_{SAT} ~ 6.5° C from tables of saturated steam and water p_{S3} must be 100% ϕ, $\therefore p_g = p_{SAT}$ = p_{S3}.

4. The mean temperature of 6.5°C and 30°C is 18.25°C or 291K. Using the data for dry air at

Dry Air at Low Pressure

T [K]	c_p [kJ/kg K]	c_v		μ 10^{-5}[kg/m s]	k 10^{-5}[kW/m K]	P_r
175	1.0023	0.7152	1.401	1.182	1.593	0.74
200	1.0025	0.7154	1.401	1.329	1.809	0.73
225	1.0027	0.7156	1.401	1.467	2.020	0.72
250	1.0031	0.7160	1.401	1.599	2.227	0.72
275	1.0038	0.7167	1.401	1.725	2.428	0.71
300	1.0049	0.7178	1.400	1.846	2.624	0.70
325	1.0063	0.7192	1.400	1.962	2.816	0.70

low pressure,

$c_{p,\text{air})291K}$ could be interpolated for accuracy, but we'll just say it's about 1.0045 kJ/kgK here.

5. Saturated water and steam table is required again,

Saturated Water and Steam

p [bar]	T [°C]	c_g [m³/kg]	u_f [kJ/kg]	u_g	h_f [kJ/kg]	h_{fg}	h_g	s_f [kJ/kg K]	s_{fg}	s_g
0.006112	0.01	206.1	0+	2375	0+	2501	2501	0+	9.155	9.155
0.010	7.0	129.2	29	2385	29	2485	2514	0.106	8.868	8.974
0.015	13.0	87.98	55	2393	55	2470	2525	0.196	8.631	8.827

This version of the table is a bit crude on temperature since it wants p first, so look at the version of the table that puts T first instead for accuracy,

Saturated Water and Steam

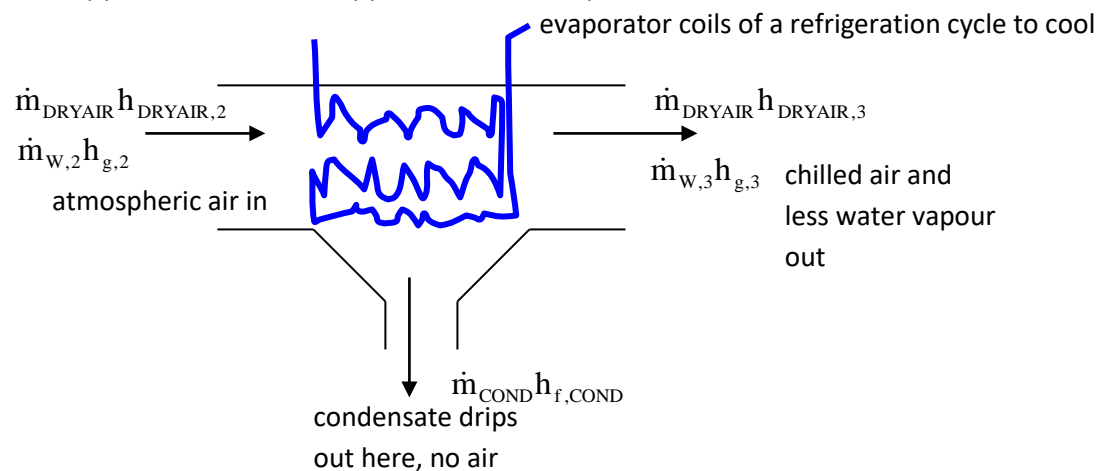| T [°C]	P_s [bar]	v_g [m³/kg]	h_f	h_{fg} [kJ/kg]	h_g	s_1
0.01	0.006112	206.1	0*	2500.8	2500.8	0†
1	0.006566	192.6	4.2	2498.3	2502.5	0.0
2	0.007054	179.9	8.4	2495.9	2504.3	0.0
3	0.007575	168.2	12.6	2493.6	2506.2	0.0
4	0.008129	157.3	16.8	2491.3	2508.1	0.0
5	0.008719	147.1	21.0	2488.9	2509.9	0.0
6	0.009346	137.8	25.2	2486.6	2511.8	0.0
7	0.01001	129.1	29.4	2484.3	2513.7	0.1
8	0.01072	121.0	33.6	2481.9	2515.5	0.1
0	0.01147	112.4	27.8	2479.6	2517.4	0.1

from which it can be seen that h_f of liquid water at 6.5°C is about 27 kJ/kg, h_g at 6.5°C is 2512.8 kJ/kg and at 30°C,

29	0.04004	34.77	121.5	2432.4	2553.9	0.4
30	0.04242	32.93	125.7	2430.0	2555.7	0.4
32	0.04754	29.57	134.0	2425.3	2559.3	0.4

h_g at 30° C is 2555 kJ/kg.

6. Use the SFEE, which is the statement of the First Law (conservation of energy) for moving fluids, and ignore the terms from kinetic and potential energy as negligible, Q+W=ΔH. In the air conditioning unit between 2 and 3, there is no fan or other working device, so W=0. We need the change in enthalpy of the fluids in the section 2 to 3 in order to work out the heat transfer to cause it.

Referring to the schematic, the enthalpy flows in at 2 and out at 3 and through the condensate collection chute, are all indicated in terms of mass flow rate and specific enthalpy. The flow of enthalpy can then be compared in the SFEE:

evaporator coils of a refrigeration cycle to cool

$\dot{m}_{DRYAIR} h_{DRYAIR,2}$

$\dot{m}_{W,2} h_{g,2}$

atmospheric air in

$\dot{m}_{DRYAIR} h_{DRYAIR,3}$

$\dot{m}_{W,3} h_{g,3}$ chilled air and less water vapour out

$\dot{m}_{COND} h_{f,COND}$

condensate drips out here, no air

$Q= \dot{m}_{DRYAIR} h_{DRYAIR,2} - \dot{m}_{DRYAIR} h_{DRYAIR,3} + \dot{m}_{W,2} h_{g,2} - \dot{m}_{W,3} h_{g,3} - \dot{m}_{COND} h_{f,COND}$

$$\dot{Q} = \dot{m}_{dry\,air} h_{dry\,air,2} - \dot{m}_{dry\,air} h_{dry\,air,3} + \dot{m}_{w2} h_{g2} - \dot{m}_{w3} h_{g3} - \dot{m}_{cond} h_{f,cond}$$

Theory note: Bear in mind here that to work out the enthalpy change of the atmospheric air, in the absence of a psychrometric chart, the h_g of the water vapour in the air, for which we can do delta H_g (H depending on mass in and outgoing on the section of interest) and for the dry air part, we have to use m_air*c_p_air*delta T because there is no table of h for dry air. So I take c_p for the approximate air in the back of the tables here. We can use $\Delta H = mC_p\Delta T$ for the enthalpy change of dry air, which is $0.495 \times 1.004 \times (30-6.5) = 11.68$ kW, just to cool the dry air. The change in enthalpy of the water vapour carried in the air, is mainly due to the loss of mass as vapour which condenses. Therefore, with the data for h_g and mass flow rate of vapour going in at 2 and out at 3, we have $0.006 \times 2555 - 0.003 \times 2485 = 5.32$kW. The condensate is assumed to leave at 6.5° C, and it has a mass rate of 0.003 kg/s, therefore enthalpy flow rate is $0.003 \times 27 = 1.27$ kW. Putting all this in the SFEE, we have Q=11.68+5.32-1.27 = 15.73 kW.

Vapour Power revision solutions Week 7

1. Carnot efficiency defines the best work out from a system – it is the ratio of the work delivered from an engine to the heat supplied at the hot end, where energy is converted to heat in order to drive the heat engine. By the 2nd Law there must be a cold end to which necessary waste heat is supplied. The work out is the difference between the heat in and the heat out. Carnot efficiency is therefore W/Q_{HOT} or $(Q_{HOT} - Q_{COLD})/Q_{HOT}$. From the 2nd Law we also know that Q is proportional to absolute temperature of the material supplying the heat flux, and so we go a step further to say that in fact the Carnot efficiency is $(T_{HOT} - T_{COLD})/T_{HOT}$ or $1 - T_{COLD}/T_{HOT}$. In this case therefore, $\eta_{CARNOT} = 1 - 300/2000 = 1 - 0.15 = 0.85$ or 85%. By the way, 2000K is impossibly hot for steel, and so cannot be practically used; typically only a few hundred degrees is usable.

2. The heat released by the coal is 30,000 kJ per kg burnt, and 50 kg/s are burnt. Therefore total energy release from coal is $50 \times 30,000 = 1,500,000$ kJ/s or kW. IFF you could use the Carnot efficiency from 1 because you had amazing materials in the machine capable of withstanding the 2,000K continuous exposure, then the work out from this machine would be W = $\eta_{CARNOT} \times 1,500,000 = 1,275,000$ kW.

3. Materials cannot withstand temperatures near their softening points, certainly not at high pressures – although the flame may be at 2000K in places, most heat transfer at that temperature is done radiatively, not by contact of the hot gas with the surfaces. The convective sections where there are steam tubes in the hot gas stream, are in gases in the order of only 1100K. Another limiter is entropy generation in the system and heat losses.