CHG2317-2717 Mid-term Fall 2017

1.[8 marks] A gaseous mixture of air and water vapour at 101325 Pa has a temperature of 80°C and a relative humidity of 40%. Then it is cooled from 80 to 15°C at a constant pressure of 101325 Pa.

(a)[3 part marks] Estimate the dew point temperature [°C] of the gaseous mixture and consequently the 'degree of superheat' when the mixture was at 80°C.
(b)[3 part marks] What is the amount of water condensed (in moles) per cubic meter of gas after the temperature of the gas mixture becomes 15°C?
(c)[2 part marks] Alternatively, the initial gaseous mixture at 80°C is placed in a container having a piston. The piston is moved to decrease the container volume and increase its pressure at constant temperature. At what pressure [bar] does the first drop of water appear?

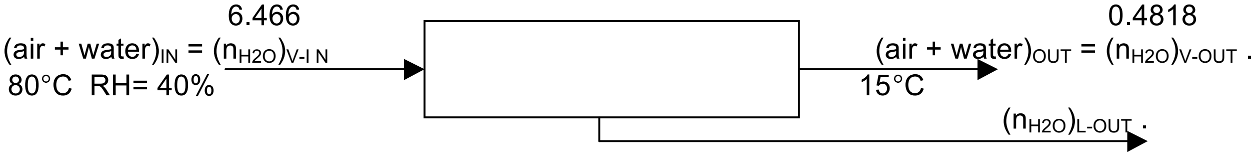
Basis of calculation=1 m^3 of gas at 80°C,40% RH,101.325 kPa–see 1(b) [1 mark for any basis of calculation]

(a) Saturated vapour pressure water at 80°C $(P^{SAT})_{80}$ =0.4736 bar =47.36 kP =47360 Pa Table B5 page 642
(47360 Pa * 760 mmHg) / 101325 Pa = 355.2 mmHg Table B.3 page 639

40% Relative humidity = 0.4 * 47360 Pa = 18944 Pa = 0.18944 bar approx 59°C Table B6 page 644
Dew point temperature = 59°C [1 mark] (18944 Pa * 760 mmHg) / 101325 Pa = 142.1 mmHg

Degrees of superheat = 80 – 59 = 21 degrees of superheat [1 mark]

(b)



at 80°C T = 273 + 80 = 353 K mol fract H_2O in = $(y_{H2O})_{IN} = \frac{p_{H2O}}{P_{TOT}} = \frac{0.18944}{1.01325} = 0.1870$ [0.5 mark]

Total gas in = $(n_{T\text{-}GAS})_{IN\text{-}80} = \frac{PV}{RT} = \frac{101325\ \text{Pa} * \frac{N}{m^2\ Pa}}{8.301\ \frac{J}{mol\ K}\ \frac{Nm}{J} * 353\ K} * 1\ m^3 = 34.579$ total moles [0.5 mark]

$(n_{H2O})_{V\text{-}IN} = (n_{T\text{-}GAS})_{IN\text{-}80} * y_{H2O} =$
$(n_{H2O})_{V\text{-}IN} = 34.579 * 0.1870 = 6.466$ moles H_2O [0.5 mark]
34.579 total moles – 6.466 moles H_2O = 28.113 moles dry air BEFORE$_{DRY\text{-}AIR}$ = AFTER$_{DRY\ AIR}$.

Saturated vapour pressure of water at 14°C, $(P^{SAT})_{14}$ = 0.01597 bar → at 16°C, $(P^{SAT})_{16}$ = 0.01817
Table B5 page 642
$(P^{SAT})_{15} = (P^{SAT})_{14} + 0.5\ [\underbrace{(P^{SAT})_{16} - (P^{SAT})_{14}}_{0.00220}]$ [0.5 mark for any interpolation]
at 15°C $(P^{SAT})_{15}$ = 0.01597 + 0.5 * (0.01817 – 0.01597) = 0.01597 +0.00110 = 0.01707 bar

at 15°C T = 273 + 15 = 288 K $(y_{H2O})_{OUT} = \frac{0.01707}{1.01325} = 0.016848$ $(y_{DRY\text{-}AIR}) = 1 - 0.016848 = 0.9832$

$(n_{T\text{-}GAS})_{OUT\text{-}15} = \frac{28.113 \text{ moles dry air}}{0.9832 \text{ mols dry air / total mol}} = 28.594$ total moles out

$(n_{H2O})_{V\text{-}OUT}$ = 28.594 total moles out * [$(y_{H2O})_{OUT}$ = 0.016848] = 0.4818 moles H_2O [0.5 mark]

Condensed H_2O = $(n_{H2O})_{L\text{-}OUT}$ = 6.466 – 0.4818 = 5.984 moles H_2O per m^3 [0.5 mark]

(c) It will condense when the H_2O partial pressure = saturation vapour pressure at 80°C

$p_{H2O} = y_{H2O} P = (P^{SAT})_{80}$ [1 mark]

$p_{H2O} = 0.187 * P = 0.4736$ bar P = 2.533 bar [1 mark]

2. [8 marks] Steam is used to provide heat to a reboiler (a heat exchanger). Steam enters the tube side of the reboiler at 190°C at 500 kPa at a flow rate of 1000 kg/h. The steam condenses in the tubes to form condensate (water in the liquid phase) that is also at a pressure of 500 kPa. The condensate leaves the reboiler through a steam trap.

(a)[5 part marks] How much heat [MJ/h] is transferred to the reboiler from the steam?

(b)[0.5 part mark] The steam (a fluid) can be considered as a system. Every thing else would be the environment. Is any work done in the above situation (yes or no)?

(c)[0.5 part mark] If so, does the steam do work on the environment, or does the environment do work on the steam?

(d)[2 part marks] Calculate the amount of work done [kJ/h].

Basis of calculation = 1000 kg/h steam [1 mark for any basis of calculation]

$$500 \text{ kPa} * \frac{1 \text{ bar}}{100 \text{ kPa}} = 5 \text{ bar}$$

Table B.7 p.650

Interpolate steam table data between superheated steam at 200°C and 151.8°C saturated steam

$$\frac{190 - 151.8}{200 - 151.8} = \frac{H\text{-}190 - 2747.5}{\underset{107.5}{2855 - 2747.5}} = \frac{V\text{-}190 - 0.375}{\underset{0.05}{0.425 - 0.375}}$$ [1 mark for any interpolation]

$$\frac{190 - 151.8}{200 - 151.8} = \frac{38.2}{48.2} = 0.7925$$

$$H\text{-}190 = 2747.5 + 0.7925 * 107.5 = 2833 \frac{\text{kJ}}{\text{kg}}$$ = Enthalpy of steam entering reboiler tubes [1 mark]

$$V\text{-}190 = 0.375 + 0.7925 * 0.05 = 0.415 \frac{\text{m}^3}{\text{kg}}$$ = Volume of steam entering reboiler tubes

$640.1 \frac{\text{kJ}}{\text{kg}}$ = Enthalpy of saturated water (condensate) about to leave reboiler tubes, prior to entering steam trap [1 mark]

$0.00109 \frac{\text{m}^3}{\text{kg}}$ = Volume of saturated water (condensate) about to leave reboiler tubes, prior to entering steam trap

HEAT transferred = enthalpy change at constant pressure

HEAT transfer in reboiler = $1000 \frac{\text{kg}}{\text{h}} * \left(2833 \frac{\text{kJ}}{\text{kg}} - 640 \frac{\text{kJ}}{\text{kg}} \right) = 2193 \frac{\text{MJ}}{\text{h}}$ [1 mark]

WORK = $-\int P dV = -P (V_{OUT} - V_{IN})$ [1 mark for formula]

$$= -500 \text{ kPa} * (0.00109 - 0.415) \frac{\text{m}^3}{\text{kg}} * 1000 \frac{\text{kg}}{\text{h}} * \frac{\text{N}}{\text{Pa m}^2} * \frac{\text{J}}{\text{N m}} = +207 \frac{\text{MJ}}{\text{h}}$$

[1 mark for correct numerical answer]

Work is performed [0.5 mark] Work is done on the fluid (on steam = on the system) [0.5 mark]

3. [3 marks] Use the compressibility factor equation of state to determine the molar volumes (L/mole) of saturated propane gas and saturated propane liquid at 78°C and 3.192 MPa.

T = 78°C 78 + 273.2 = 351.2 K Tc = 369.9 K Tr = T / Tc = 351.2 / 369.9 = 0.949
0.5 mark for the correct critical temperature

Fig 5.4-1 Felder Rousseau Bullard z (gas) = 0.59 Intersection of Tr and saturated gas line = Pr = 0.75
z(liquid) = 0.1 from intersection of Pr = 0.75 and saturated liquid line
0.5 mark if at least one the “z” values is correct

Pc = 42 atm $P = PR * P_C = 0.75 * 42$ atm = 31.5 atm * 101.3 kPa /atm = 3192 kPa = 3.192 MPa
0.5 mark for the correct pressure

$$V_{GAS} = \frac{z\,RT}{P} \leftarrow$$ 1 mark for the correct formula for the compressibility factor equation of state

$$V_{GAS} = \frac{z\,RT}{P} = 0.59 * \frac{\frac{8.314\ J}{mole\ K} * \frac{N\ m}{J}\ 351.2\ K}{3{,}192{,}000\ Pa * \frac{N}{m^2\ Pa}} = 0.540 * 10^{-3}\ \frac{m^3}{mole} * 10^3\ \frac{L}{m^3} = 0.540\ \frac{L}{mole}$$

$$V_{LIQUID} = \frac{z_{GAS}\,RT}{P} * \frac{z_{LIQUD}}{z_{GAS}} = 0.540\ \frac{L}{mole} * \frac{0.1}{0.59} = 0.0915\ \frac{L}{mole}$$

0.5 mark if one of the “V” values is correct

~~Tc = 369.9 K Pc = 42 atm T = Tr * Tc = 0.95 * 369.9 = 351.4 = 78.2 C~~
~~P = Pr * 42 = 0.75 * 42 = 31.5 atm = 3191.7 kPa~~

4.[3 marks] A gaseous phase mixture of air and acetone is inside a rigid container. It is at equilibrium with liquid phase acetone at a temperature of 40°C and a pressure of 5000 mmHg. Gaseous mixtures of air and acetone containing between 2.6 and 13% mol acetone are known to burn explosively if they are exposed to a flame or a spark. Determine whether or not there is a risk of an explosion occurring in the gaseous mixture that is inside the rigid container.

$F = C + \pi - 2 = 2 + 2 - 2 = 2$ Specify T = 40°C and P = 5000 mmHg

Antoine Equation p. 246 – empirical equation

$$\log_{10} P^{SAT} = A - \frac{B}{T + C}$$ T °C, P mmHg A, B, C = constants page 640, Table B-4
[1 mark for correct Antoine equation]

$$\log_{10} P^{SAT} = 7.11714 - \frac{1210.595}{40 + 229.664}$$ Eq 6.1-4 A =7.11714 B = 1210.595 C = 229.664
[1 mark for correct constants]

$$\log_{10} P^{SAT} = 7.1174 - 4.48927 = 2.62783$$

P^{SAT} = 424.5 mmHg [0.5 mark]

$$y_{ACETONE} = \frac{424.5}{5000} = 0.085$$ = 8.5 % acetone in vapour mixture = risk of explosion [0.5 mark]

5. [3 marks]How much heat (kJ) is required to change the temperature of a mixture of nitrogen (mole fraction = 0.7) and water (mole fraction = 0.3) from 100°C to 500°C at 1 atmosphere.

$\Delta Q = \Delta H$ when P = constant

Table B.8 Felder Rousseau and Bullard

Basis of calculation = 1 mole of gas mixture ← 1 mark for any basis of calculation

At constant pressure Q = ΔH = mole fraction * [H(500°C) – H(100°C)] = $\Delta H_{COMPONENT}$ =
1 mark for the above formula

Component	mole fraction	H(500°C) kJ/mol	H(100°C) kJ/mol	$\Delta H_{COMPONENT}$ kJ/mol
N_2	0.7	14.24	2.19	8.43
H_2O .	0.3	17.01	2.54	4.34
Total				12.77

Heat required = 12.77 kJ/mole of N_2–H_2O mixture ← 1 mark for the correct answer.

Extra Question – not used

[3 marks] Methane (CH_4) is burned in 20% excess air. Determine the composition (mole %) of the methane-air mixture that enters the burner.

Basis of calculation = 1 mole methane ← 0.5 mark for any basis of calculation

$CH_4 + 2\,O_2 = CO_2 + 2\,H_2O$ ← 1 mark

Component	Moles	Mole fraction
CH_4 .	1	0.114
O_2 .	2 * 1.2 = 2.4	0.274
N_2 .	2.4 * (0.79/0.21) = 5.37	0.612
CO_2 .	0	
H_2O		
Total	8.77	1.000

0.5 mark for multiplying the O_2 moles by 1.2
0.5 mark for knowing the 0.79 / 0.21 air composition
0.5 mark for the correct composition (mole fractions)

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