CE 407Notes

Absorption tower Example

A gas stream of 800 m^3/hr has a composition of 80 mole percent air and 20 mole percent ammonia. A courtercurrent tower will use water to clean the gas and will operate isothermally at 20 C and atmospheric temperature. The exiting gas must have the ammonia concentration reduced to 1 mole percent or lower.

- What is the minimum flow rate of water required to achieve the desired cleanup, corresponding to an infinite number of stages?
- How many ideal stages will be required if we use 1.15 times the minimum flow rate of water?

Equilibrium data applicable at 20 °C are as follows:

liquid phase composition expressed as g NH_3 per 100 g H_2O	vapor phase composition expressed as partial pressure of NH_3 in mm Hg
2.0	12.0
2.5	15.0
3.0	18.2
4.0	24.9
5.0	31.7
7.5	50.0
10	69.6
15	114
20	166
25	227

(i) Convert equil. data to mole fraction x, y

Sample calc. for 2nd line of table:

$$2\,g\ NH_3 \times \frac{1\ mol\ NH_3}{17.031\ g\ NH_3} = 0.11743\ mol\ NH_3$$

$$100\,g\ H_2O \times \frac{1\ mol\ H_2O}{18.015\ g\ H_2O} = 5.5509\ mol\ H_2O$$

$$x = \frac{0.11743}{0.11743 + 5.5509} = 0.0207$$

$$y = y_i = \frac{y_i P}{P} = \frac{p_i}{P} = \frac{12.0\ mmHg}{760\ mmHg} = 0.0158$$

Equil. curve

x	y
0	0
0.0207	0.0158
0.0258	0.0197
0.0308	0.0239
0.0406	0.0328
0.0502	0.0417
0.0735	0.0658
0.0957	0.0916
0.1369	0.1500
0.1746	0.2184
0.2091	0.2987

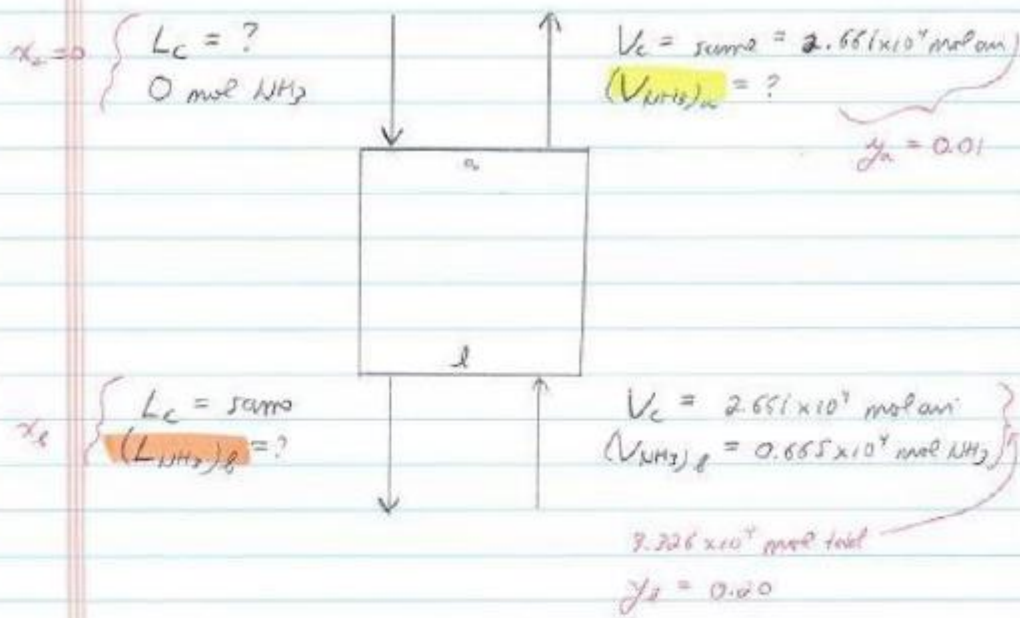
← understood; equil. curve always passes through (0,0)

-or- can use spreadsheet

(ii) Preliminaries + material balance (1 h basis)

Entering gas:

$$800\ m^3 \times \frac{101325\ Pa}{(8.314\ J/mol\,K)(293.15K)} = 3.326\times10^4\ mol$$



$$y_a = 0.01 = \frac{(V_{NH_3})_a}{(V_{NH_3})_a + 2.661\times10^4\,mol}$$

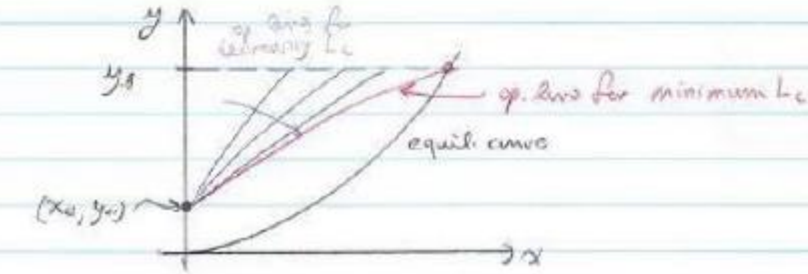
$$\Rightarrow (V_{NH_3})_a = 0.027\times10^4\ mol\ NH_3$$

Then NH_3 balance $\Rightarrow$

$$(L_{NH_3})_ℓ = (0.665 - 0.027)\times10^4\ mol\ NH_3$$
$$= 0.638\times10^4\ mol\ NH_3$$

(iii) Minimum liquid

Logic as usual:



Because equil. curve is concave up, 1st contact occurs at "b" end of op. line. ∴ for minimum liquid

$y_b = y^*(x_b) =$ y in equil. w/ x_b

or $x_b = x^*(y_b) =$ x in equil. w/ y_b

By linear interpolation, pt. of equil. curve with $y = 0.20$ have $x = 0.1645$

$$\therefore (x_b)_{\text{min. liquid}} = 0.1645 = \frac{0.638 \times 10^4 \text{ mol}}{0.638 \times 10^4 \text{ mol} + (L_c)_{min}}$$

$\Longrightarrow$

$$\boxed{(L_c)_{min} = 3.240 \times 10^4 \text{ mol/h}} \leftarrow \textbf{answer (a)}$$

(iv) Operation with actual amt. of liquid

Use $L_c = (1.15)(\underbrace{3.240 \times 10^4 \text{ mol}}_{(L_c)_{min}}) = 3.726 \times 10^4 \text{ mol } H_2O$

Then $x_b = \dfrac{0.638 \times 10^4}{(0.638 + 3.726) \times 10^4} = 0.1462$

Calculate a few intermediate points on operating line using formula

3.726 × 10⁴ mol

$$y_{n+1} = 1 - \left[\frac{L_c}{V_c} \left(\frac{1}{1-x_n} - \frac{1}{1-x_a} \right) + \frac{1}{1-y_a} \right]^{-1}$$

$L_c = 3.726 \times 10^4$ mol, $V_c = 2.661 \times 10^4$ mol, $x_a = 0$, $y_a = 0.01$

$x_n \Leftrightarrow x$, $y \Leftrightarrow y_{n+1}$

Op. line

x	y	
0	0.01	← "a" end
0.04	0.0641	
0.08	0.1165	
0.12	0.1674	
0.1462	0.20	← "b" end

- or - can use spreadsheet

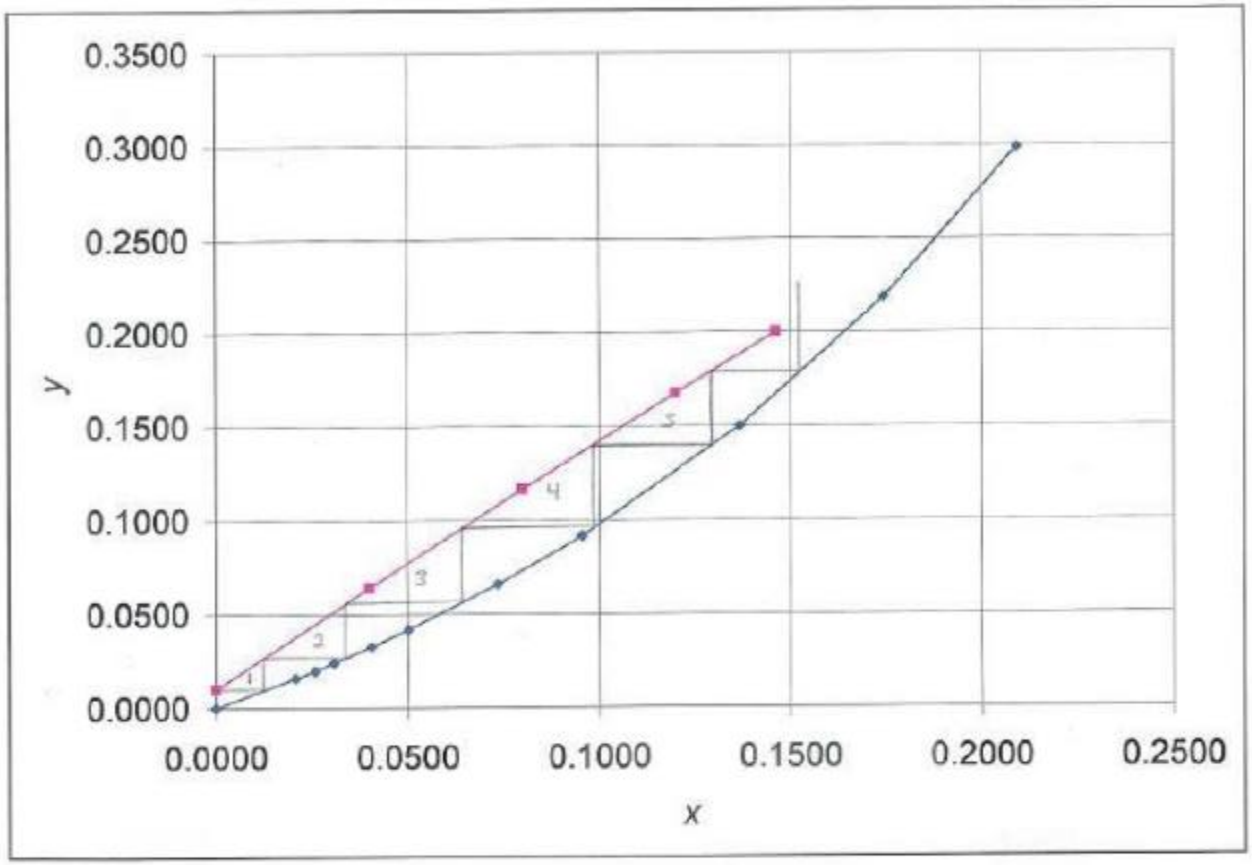
(v) Operating diagram

Graph on next page. Count steps.

will need ≈ 5.7 ideal stages ⟹ 6 ideal stages

round up for safety factor in design

answer (b)


0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
y
0.0000
0.0500
0.1000
0.1500
0.2000
0.2500
x
1
2
3
4
5

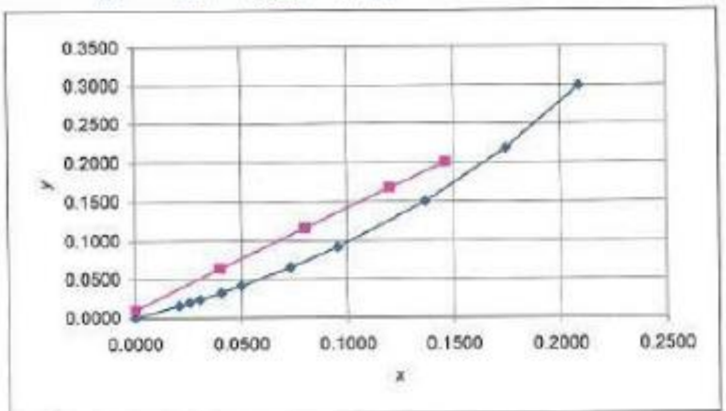
5

EQUIL

g NH3 per 100 g H20	partial pressure of NH3	x	y
0	0	0.0000	0.0000
2	12	0.0207	0.0158
2.5	15	0.0258	0.0197
3	18.2	0.0308	0.0239
4	24.9	0.0406	0.0328
5	31.7	0.0502	0.0417
7.5	50	0.0735	0.0658
10	69.6	0.0957	0.0916
15	114	0.1369	0.1500
20	166	0.1746	0.2184
25	227	0.2091	0.2987

OP

x	y
0	0.01
0.04	0.064059
0.08	0.116498
0.12	0.167389
0.1462	0.199915



=A5/17.031/(A5/17.031+100/18.015)

=1-1/(37260/26610*(1/(1-F4)-1/(1-0))+1/(1-0.01))