CE 407 Stripping Tower Example

A 100 mol/min of a solution with composition 95 mole percent oil, 5 mole percent benzene must be cleaned up. A stripping tower that will operate at 26.1 C and atmospheric pressure will be used. The exiting liquid benzene mole fraction must be reduced to 0.001. The entering air will be pure. If we are to use 1.3 times the minimum air flow rate how many ideal stages will be required? Assume that Raoult's law is valid for this system. The saturated vapor pressure of benzene at 26.1 C is 100 mm Hg.

(i) Equil relation.

Raoult's law for benzene:

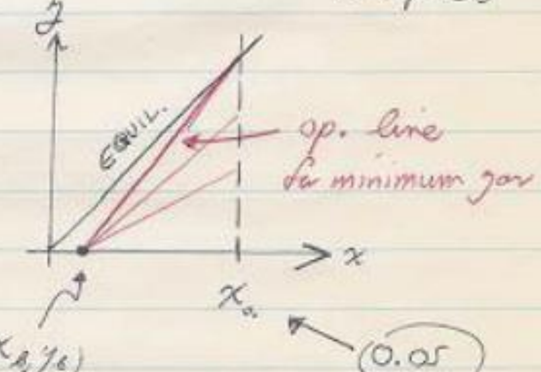
$y_{benz} p = x_{benz} P^{sat}_{ben}$ (1 atm → p)

so

$$y = \left(\frac{P^{sat}_{benz}}{p}\right) x = \left(\frac{100 \text{ mmHg}}{760 \text{ mmHg}}\right) x$$

$$y = 0.1316\, x$$ ← plot on graph paper (see p. (9))

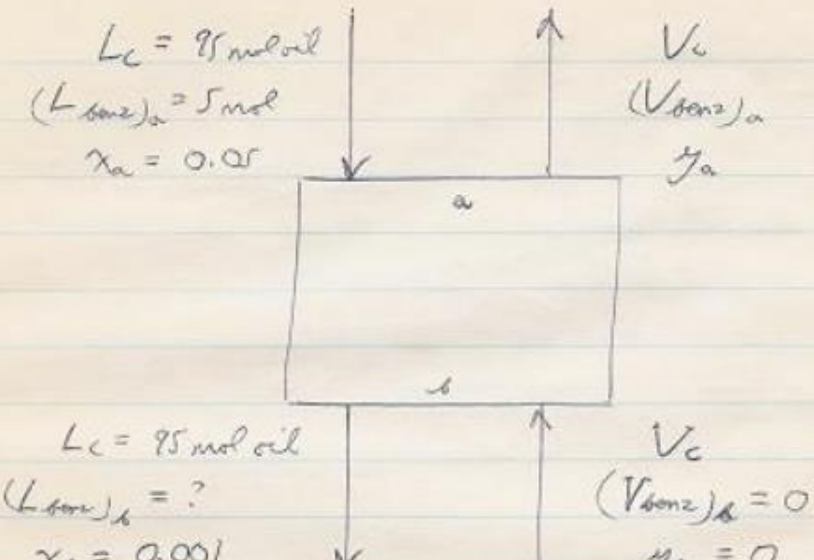
(ii) Minimum gas



Op. line for minimum gas just touches equil. curve at $x = x_a$, so

$$(y_a)_{\min gas} = y^{equil}(x_a)$$
$$= (0.1316)\, x_a = (0.1316)(0.05)$$
$$= 0.00658$$

Now...



By def. of mole fraction,

$$0.001 = \frac{(L_{benz})_b}{95 \text{ mol} + (L_{benz})_b}$$

$$\Rightarrow (L_{benz})_b = 0.0951 \text{ mol benzene}$$

By benzene balance,

$$(V_{benz})_a = (L_{benz})_a - (L_{benz})_b$$
$$= 5 \text{ mol} - 0.0951 \text{ mol}$$
$$= 4.9049 \text{ mol}$$

Finally, $$(y_a)_{min.\,gas} = 0.00658 = \frac{4.9049 \text{ mol}}{(V_c)_{\substack{min\\gas}} + 4.9049 \text{ mol}}$$

$$\Rightarrow$$

$$(V_c)_{min.\,gas} = 740.5 \text{ mol air}$$

(iii) Terminal concentration y_a for actual amount of gas used

$$V_c = (1.3)(740.5 \text{ mol}) = 963 \text{ mol air}$$

Then

$$y_a = \frac{4.9049 \text{ mol}}{(963 + 4.9049) \text{ mol}} = 0.00507$$

(iv) Operating line for actual amount of gas used.
Choose a few arbitrary values of x_n between x_b and x_a, i.e., $0.001 < x_n < 0.05$ and calculate y_{n+1} from material balance relation

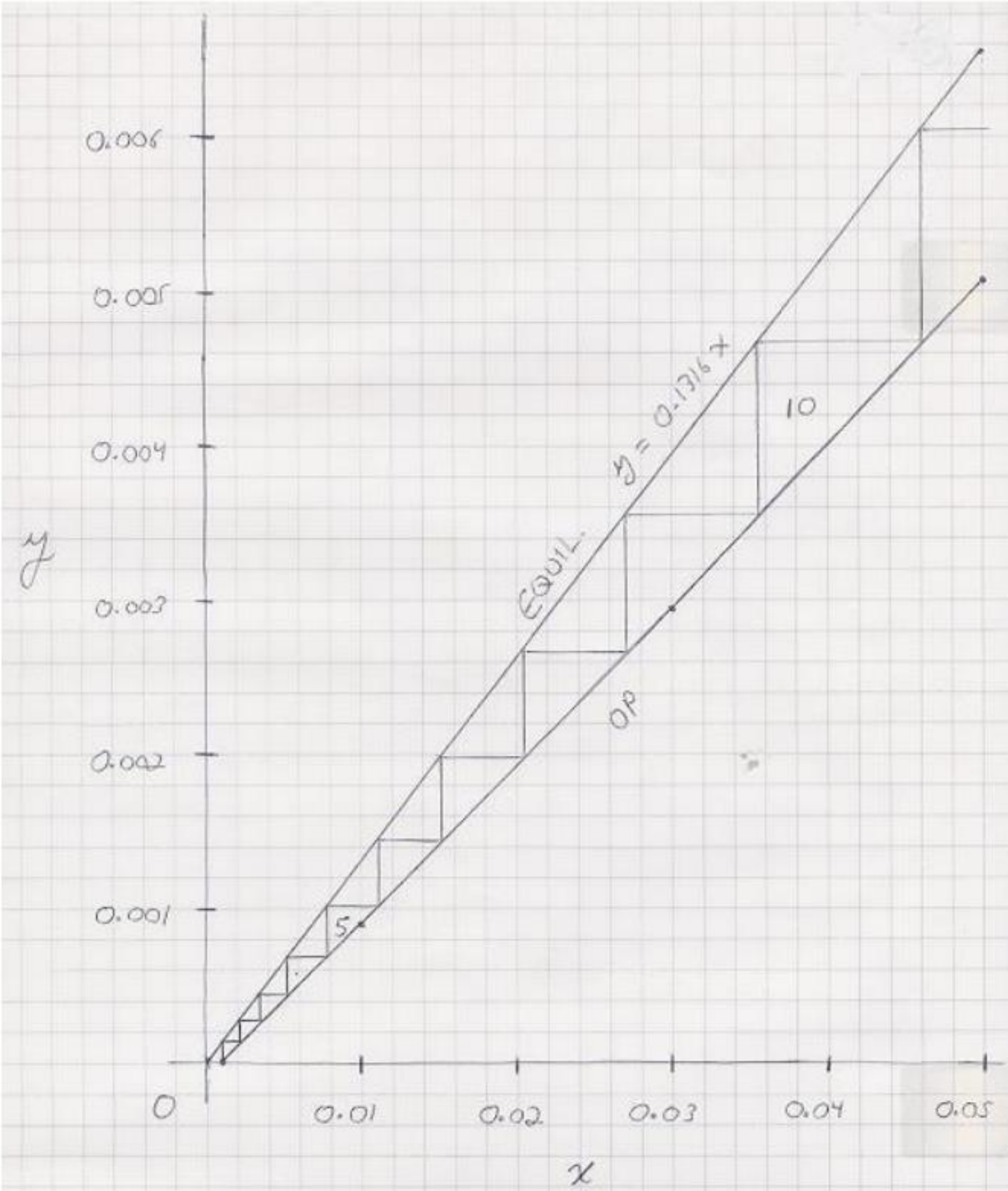
$$y_{n+1} = 1 - \left[\frac{L_c}{V_c} \left(\frac{1}{1-x_n} - \frac{1}{1-x_a} \right) + \frac{1}{1-y_a} \right]^{-1}$$

(L_c = 95 mol; V_c = 963 mol; x_a = 0.05; y_a = 0.00507)

Make table:

	x_n	y_{n+1}
$(x_a, y_a) \rightarrow$	0.05	0.00507
	0.03	0.00295
	0.01	0.00090
$(x_b, y_b) \rightarrow$	0.001	0

Plot op. line on the graph.


0.006
0.005
0.004
0.003
0.002
0.001
y
0
0.01
0.02
0.03
0.04
0.05
x
EQUIL.
y = 0.1316 x
OP
5
10

(v) Count steps

From graph, need about 10.3 ideal stages. Round up to [11 ideal stages] ← for safety factor.

(vi) (NOT REQUIRED)

Equil. curve here is straight line. Dilute solutions ⇒ op. line very nearly straight line also. ∴ Eq. (17-28) should be good approx.

(equil. $x = \frac{y}{0.1316}$)

$$x_a = 0.05$$

$$x_a^* = x^*(y_a) = \frac{y_a}{0.1316} = \frac{0.00507}{0.1316} = 0.0385$$

$$x_b = 0.001$$

$$x_b^* = x^*(y_b) = \frac{y_b}{0.1316} = \frac{0}{0.1316} = 0$$

$$N = \frac{\ln\left[\frac{(x_a - x_a^*)}{(x_b - x_b^*)}\right]}{\ln\left[\frac{(x_a - x_b)}{(x_a^* - x_b^*)}\right]} = \frac{\ln\left(\frac{0.05-0.0385}{0.001-0}\right)}{\ln\left(\frac{0.05-0.001}{0.0385-0}\right)}$$

= 10.1 ideal stages. close!

Eq. (20.24): can also be used:

$$y_a = 0.00507$$

$$y_a^* = y^*(x_a) = (0.1316)(0.05) = 0.00658$$

$$y_b = 0$$

$$y_b^* = y^*(x_b) = (0.1316)(0.001) = 0.0001316$$

$$N = \frac{\ln\left((y_b - y_b^*)/(y_a - y_a^*)\right)}{\ln\left((y_b - y_a)/(y_b^* - y_a^*)\right)}$$

$$= \frac{\ln\left(\frac{0 - 0.0001316}{0.00507 - 0.00658}\right)}{\ln\left(\frac{0 - 0.00507}{0.0001316 - 0.00658}\right)} = 10.1$$

[illegible] Eq. 20

same answer!