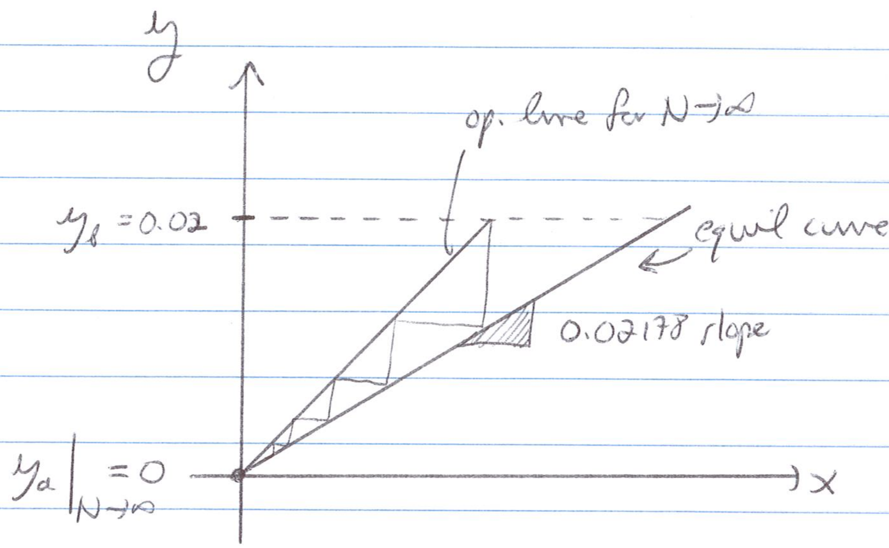
CE 407 Exam #01 SOLUTION

Problem 1

(a) Op. line ≈ line w/ slope $L/V \approx 3/80 = 0.0375$

Equil. curve $y = (p^{sat}/P)x$
$= (16.55/760)x = 0.02178\,x$

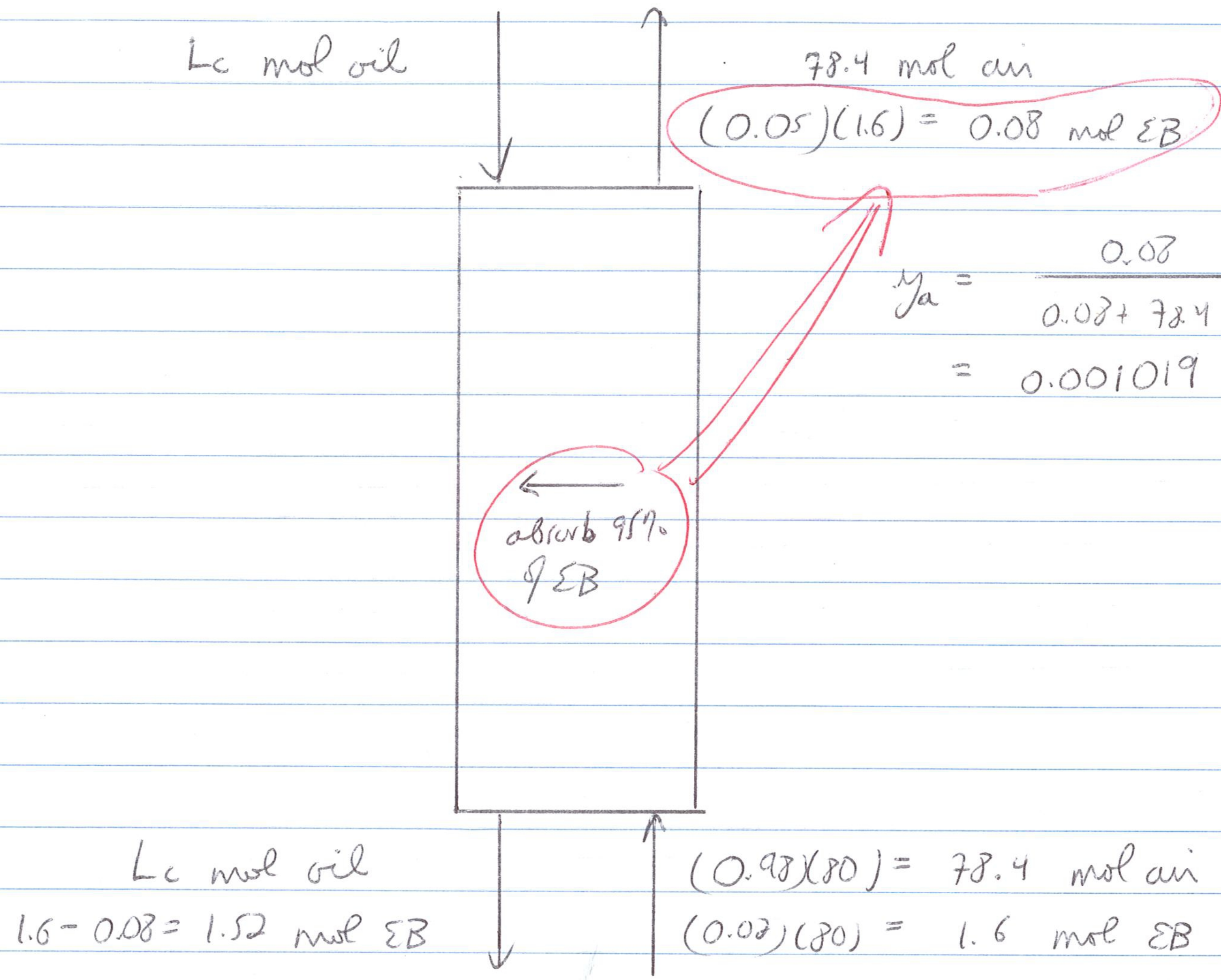
Op. line has bigger slope than equil. curve.
∴ as $N \to \infty$ can make y_a arbitrarily small.



$y_a\big|_{N\to\infty} = 0$ (arbitrarily pure air)

WOW!

(b) (1 h basis)



$$y_a = \frac{0.08}{0.08 + 78.4}$$

$$= 0.001019$$

For actual op., $L_c = 2$ mol oil

$$x_b = \frac{1.52}{2+1.52} = 0.4318$$

Intermediate pt. on op. line

	x	y
(x_a, y_a)	0	0.001019
	0.2	0.007343
(x_b, y_b)	0.4318	0.02

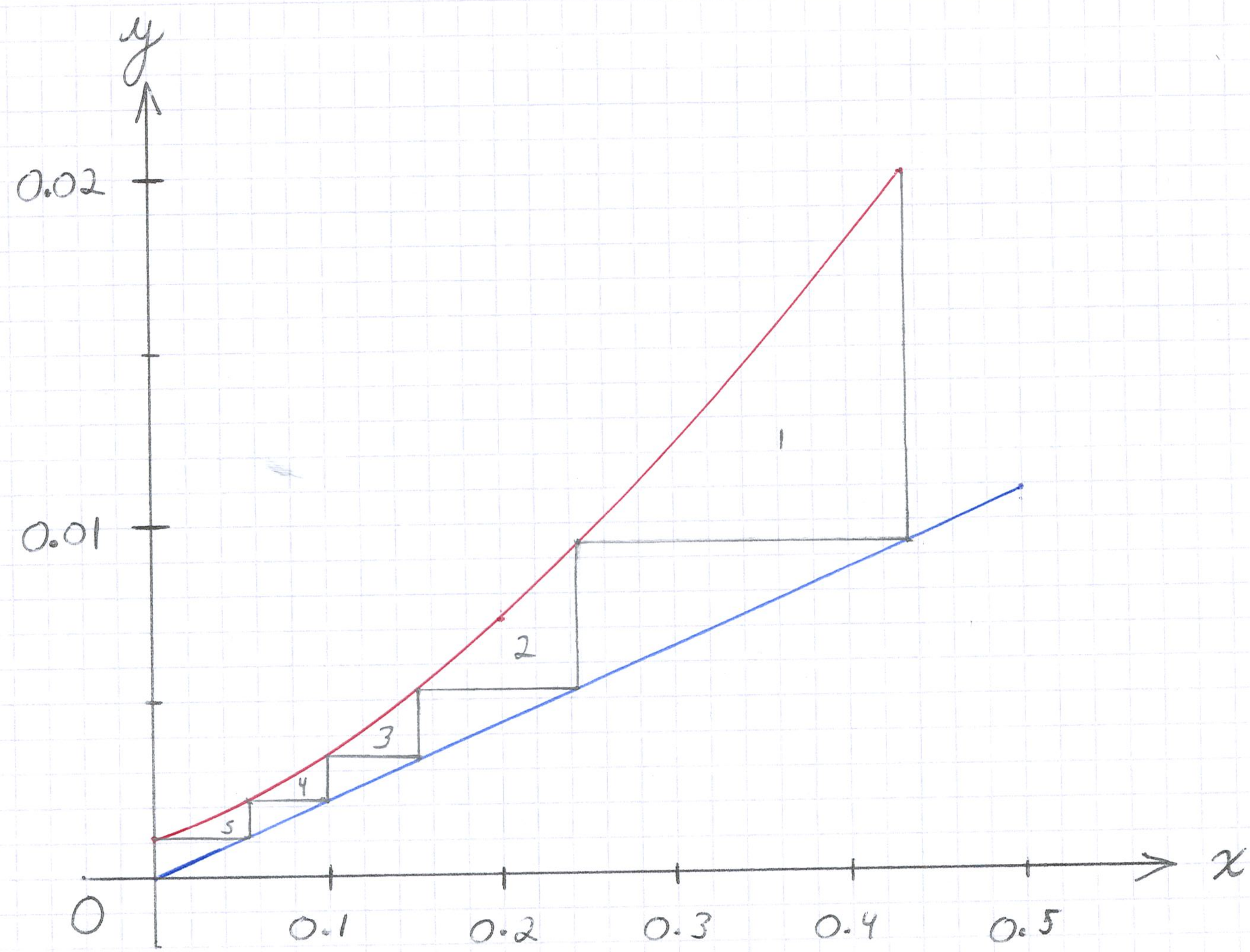
$$y = 1 - \left[\frac{L_c}{V_c}\left(\frac{1}{1-x} - \frac{1}{1-x_a}\right) + \frac{1}{1-y_a}\right]^{-1}$$

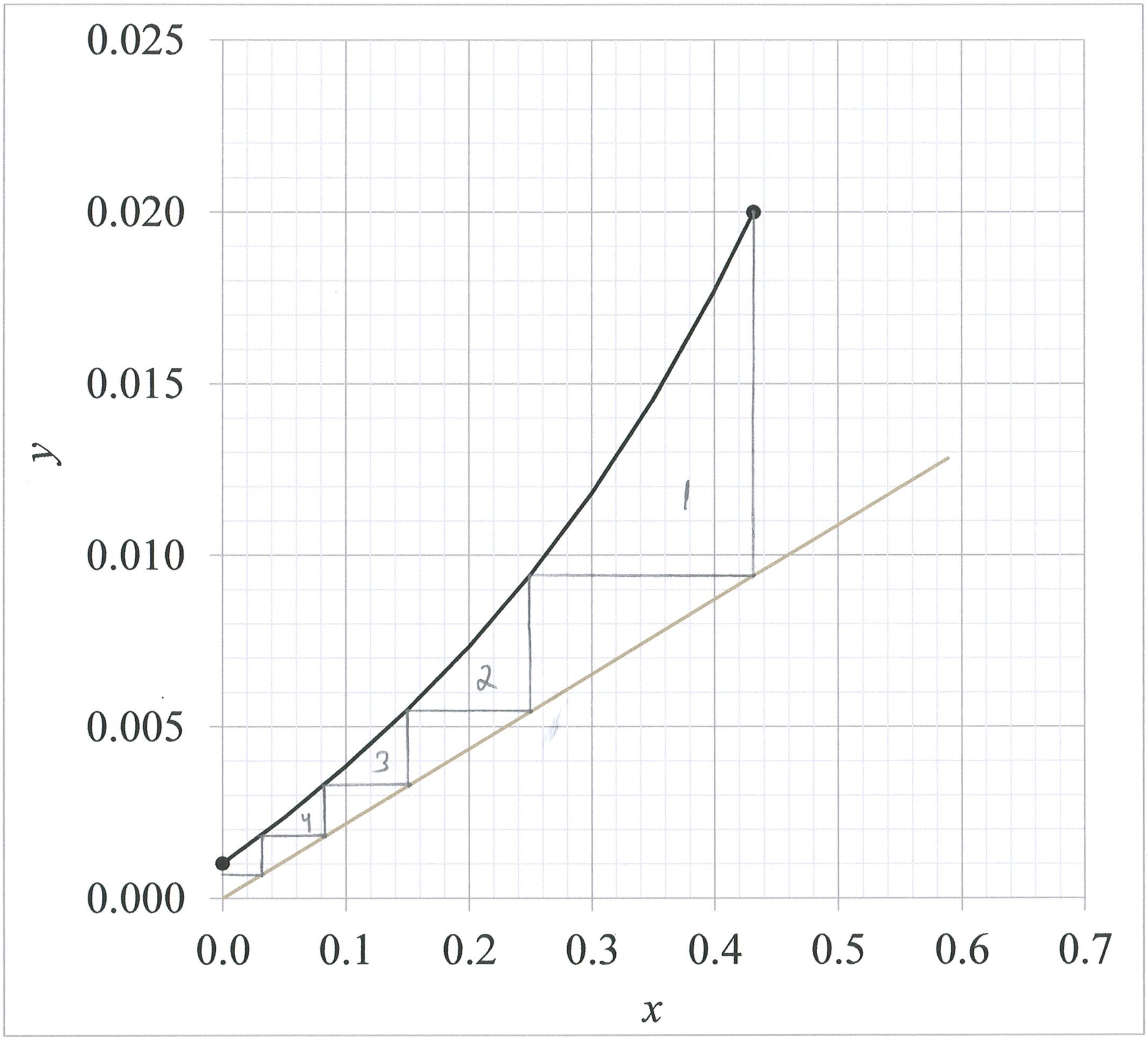
$$= 1 - \left[\frac{2}{78.4}\left(\frac{1}{1-0.2} - \frac{1}{1-0}\right) + \frac{1}{1-0.001019}\right]^{-1}$$

$$= 0.007343$$

From graph, need ≈ 4.9 or 5 stages ⇒ 5 stages

Graph paper for #1

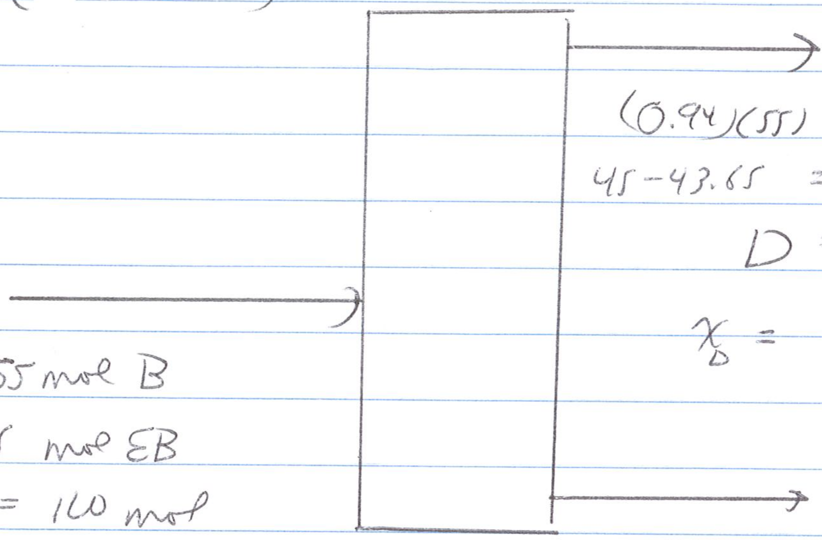




(Clearly a spreadsheet could not be prepared during the exam; this is just for greater accuracy)

Problem 2

(a) (100 mol basis)



$(0.94)(55) = 51.7$ mol B

$45 - 43.65 = 1.35$ mol EB

$D = 53.05$ mol

$x_D = \dfrac{51.7}{53.05} = 0.975$

55 mol B

45 mol EB

$F = 100$ mol

$x_F = 0.55$

$55 - 51.7 = 3.3$ mol B

$(0.97)(45) = 43.65$ mol EB

$B = 46.95$ mol

$x_B = \dfrac{3.3}{46.95} = 0.070$

R-op. line: $(x_D, x_D) = (0.975, 0.975)$. Intercept $x_D/(R+1) = 0.975/(0.6+1) = 0.609$

feed line: $(x_F, x_F) = (0.55, 0.55)$. Sat. liq. feed $\Rightarrow$ vertical

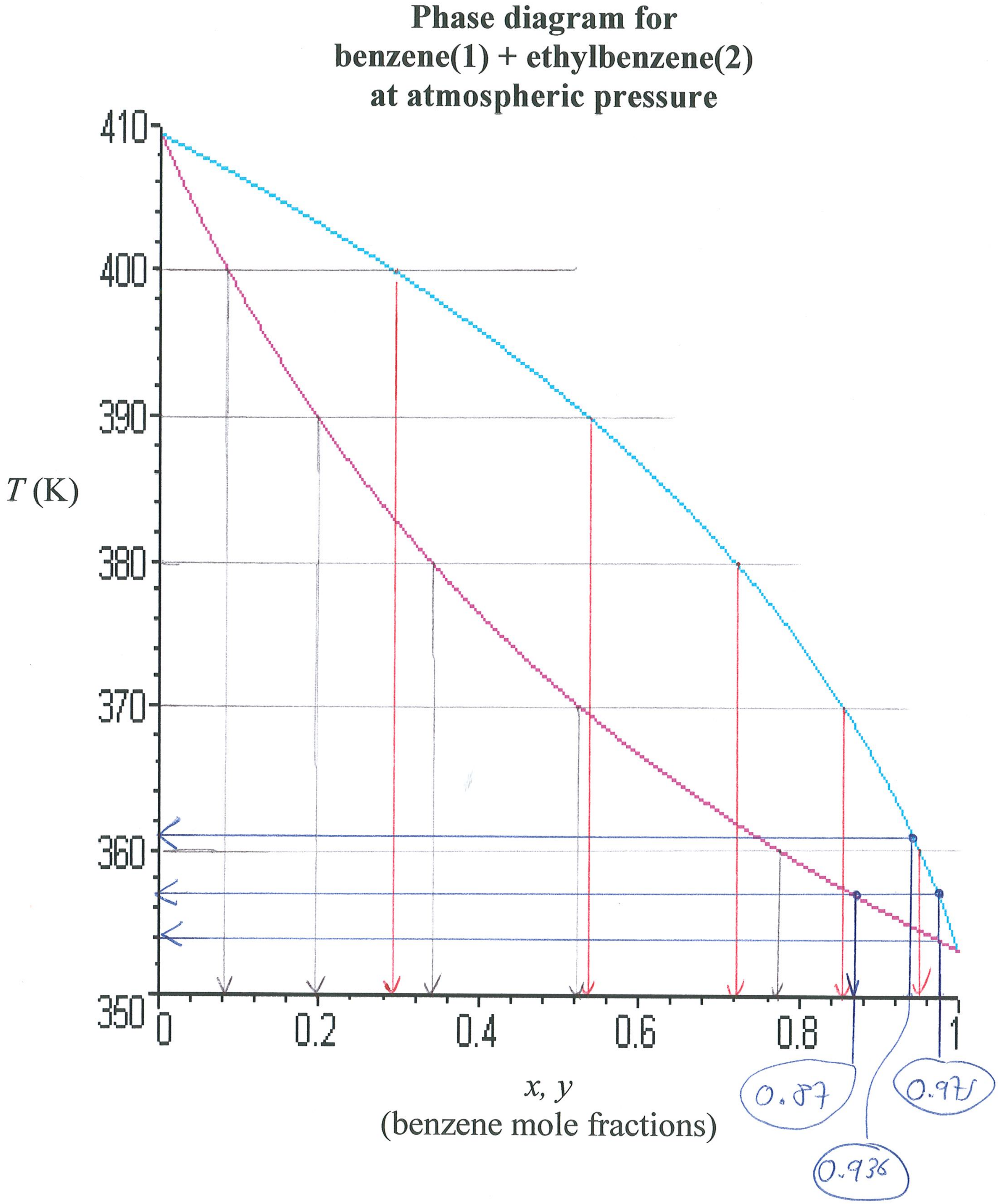
S-op. line: Passes through $(x_B, x_B) = (0.070, 0.070)$ and intersection of feed and R-op. lines

Equil. curve: Read from phase diagram

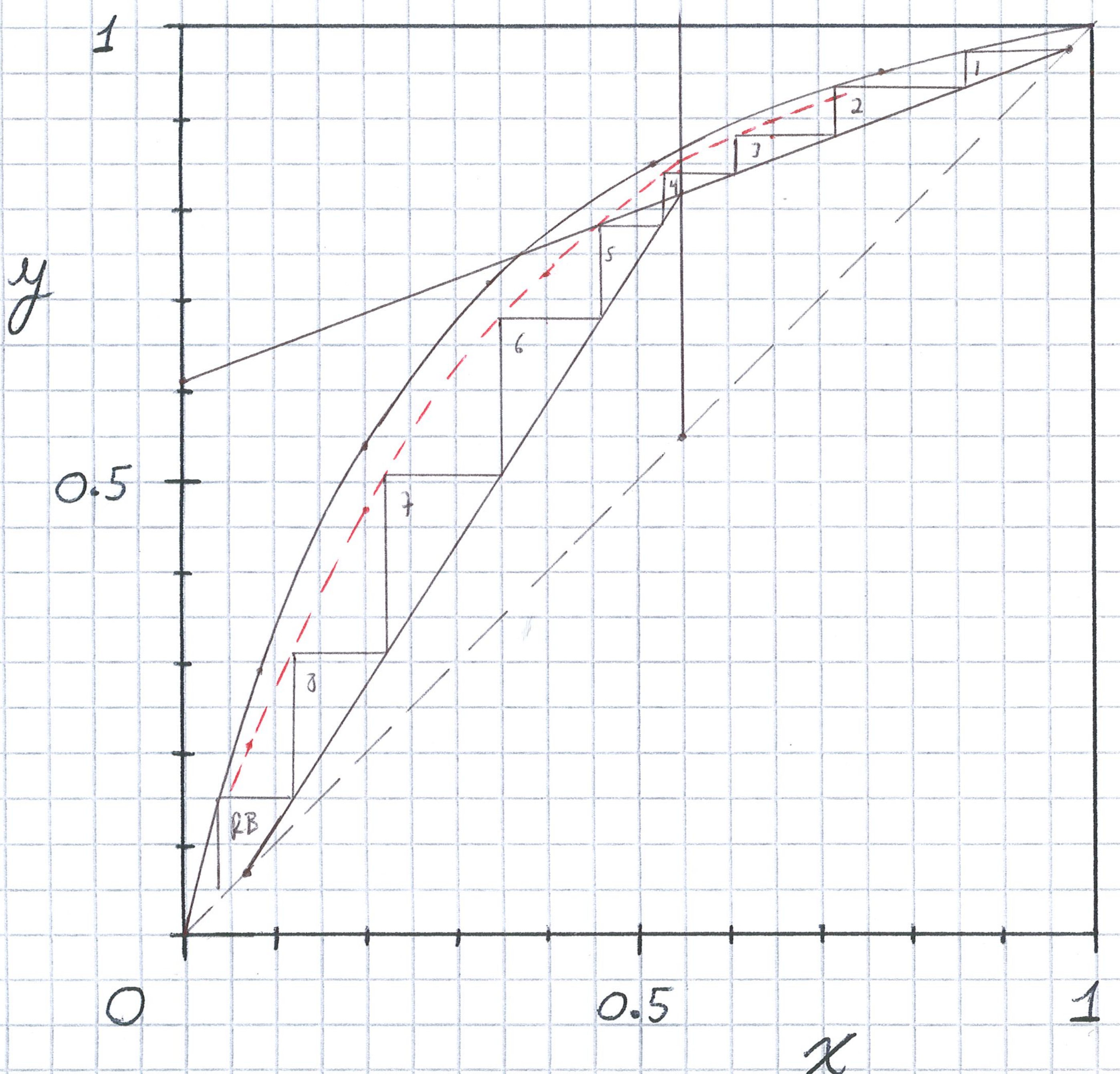
T( )	$\bar{x}$	$\bar{y}$
409	0	0
400	0.08	0.29
390	0.20	0.54
380	0.34	0.72
370	0.52	0.85
360	0.77	0.95
353	1	1

First two stages – $\eta_M = 100\%$
Thereafter – $\eta_M = 75\%$; draw auxiliary stepping curve

See op. diagram – **need 8 trays in column** (+ RB)
(~7.6 trays => round up for safety factor)


Phase diagram for
benzene(1) + ethylbenzene(2)
at atmospheric pressure
410
400
390
380
370
360
350
T (K)
0
0.2
0.4
0.6
0.8
1
x, y
(benzene mole fractions)
0.87
0.936
0.975

Graph paper for #2



(b) <u>Formulas for enthalpy</u> ref. state: H = 0 for both pure liquids @ 80°C (n.b.p. of benzene)

pure liquid benzene

$$H_x = 0 + 159(T-353)$$

pure liquid ethylbenz

$$H_x = 0 + 231(T-353)$$

pure vapor benzene

$$H_y = 0 + 30{,}794 + 104(T-353)$$

pure vapor ethylbenzene

$$H_y = 0 + 231(409-353) + 35{,}815 + 160(T - 353 + 353 - 409)$$

$$= 35{,}815 + (231-160)(409-353) + 160(T-353)$$

$$= 39{,}791 + 160(T-353)$$

$$H_x(T,x) = x\left[0 + 159(T-353)\right] + (1-x)\left[0 + 231(T-353)\right]$$

$$\boxed{H_x(T,x) = (231 - 72x)(T-353)}$$

$$H_y(T,y) = y\left[30{,}794 + 104(T-353)\right] + (1-y)\left[39{,}791 + 160(T-353)\right]$$

$$\boxed{H_y(T,y) = 39{,}791 - 8997y + (160-56y)(T-353)}$$

<u>Enthalpies</u>

$H_{x,0} = H_D$: sat. liquid w/ $x = 0.975$

⇒ <u>$T = 354$ K</u> from phase diagram

⇒ $H =$ J/mol from $H_x(T,x)$ formula

$H_{y,1}$: sat. vapor w/ $y = 0.975$

⇒ $T = 357$ K from phase diagram

⇒ $H = 31{,}441$ J/mol from $H_y(T,y)$ formula

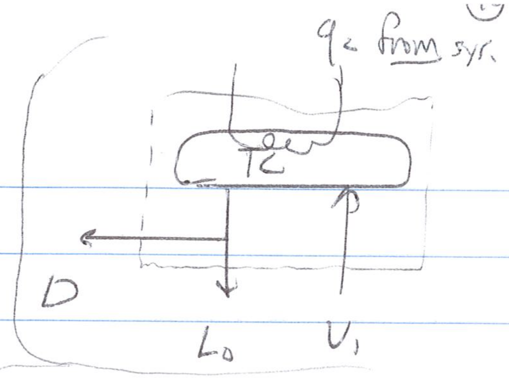
(same)

<u>Enthalpy balance</u> $D H_D + L_0 H_{x,0} - V_1 H_{y,1} = -q_c$

or $q_c = V_1 H_{y,1} - \underbrace{(L_0 + D)}_{V_1} H_{x,0}$

$= V_1 (H_{y,1} - H_{x,0})$

$= (84.88 \text{ mol})(31{,}441 - 161) \text{ J/mol}$



$q_c = 2.655 \times 10^6$ J per 100 mol of feed (basis)

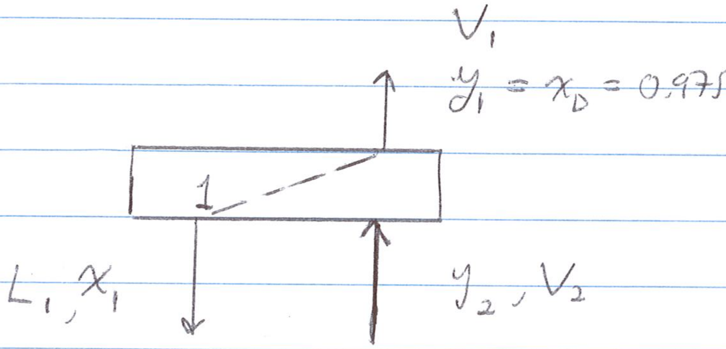
$V_1 = D + L_0 = D + RD$

$= (1+R)D$

$= (1.6)(53.05 \text{ mol})$

$= 84.88$ mol

(c)



From phase diagram, L from stage 1 has $x_1 = 0.87$ (liquid in equil. w/ vapor w/ $y_1 = 0.975$).

Material balance (op. line)

$$y_2 = \frac{R}{R+1} x_1 + \frac{x_D}{R+1} = \left(\frac{0.6}{1.6}\right)(0.87) + \frac{0.975}{1.6}$$

$y_2 = 0.936$

From phase diagram, V into stage 1 (from stage 2) has temp **$T = 361$ K** (sat. vapor with $y = 0.936$).