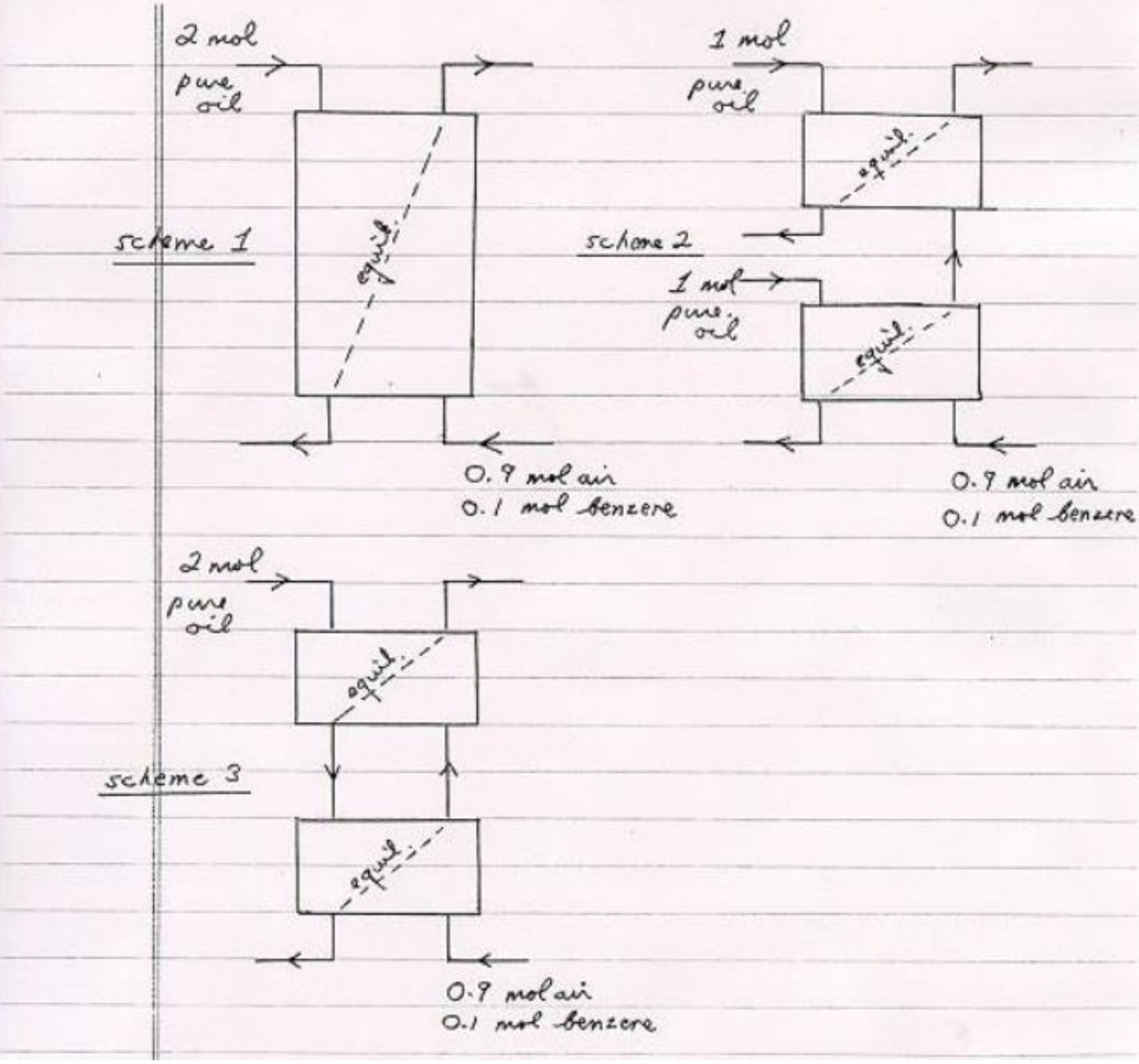
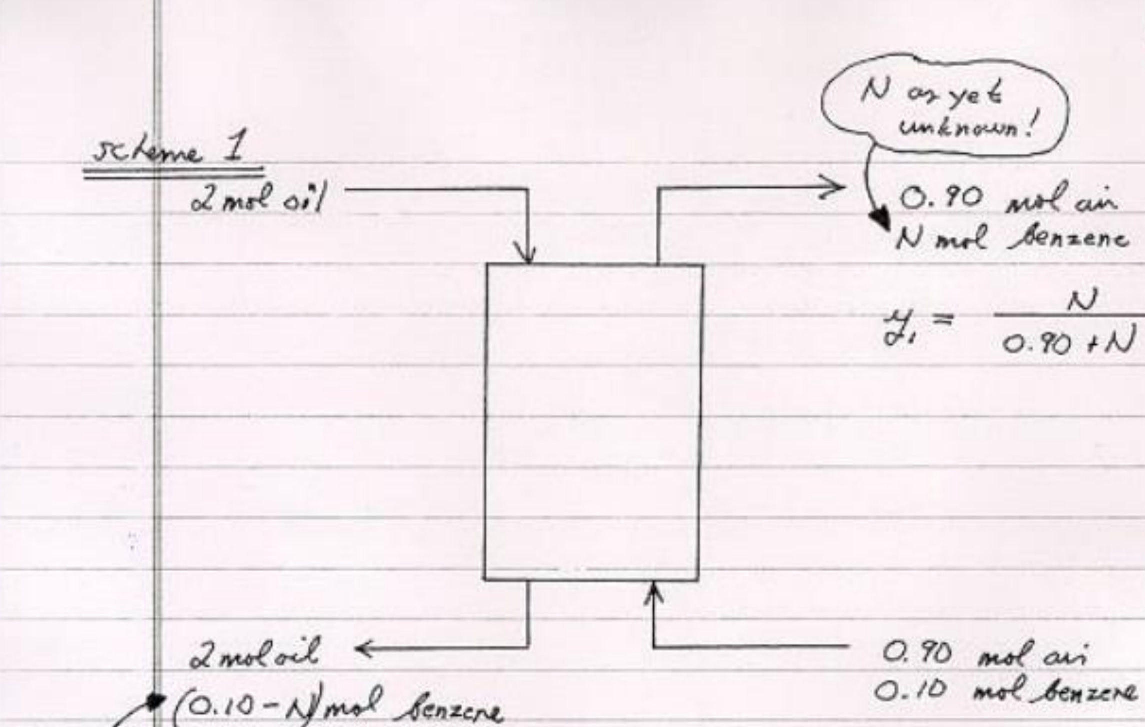
CE 407 Notes
Countercurrent Contact

Absorption: outcomes of different schemes for gas-liquid contact

1.0 mol of a contaminated gas stream (composition 90 mole percent air, 10 mole percent benzene) is contacted with 2.0 mol of an absorption oil in order to remove some of the benzene. Determine the benzene mole fraction in the exiting gas stream for each of the three schemes indicated below. Neglect any evaporation of oil, as well as dissolution of air in the liquid. The equilibrium relation is $y = 2.5\,x$.



scheme 1



$$y_1 = \frac{N}{0.90 + N}$$

$$x_1 = \frac{0.10 - N}{2 + (0.10 - N)}$$

(equil. relation between y_1 and x_1)

Exiting streams at equilibrium $\Rightarrow$ $y_1 = 2.5\, x_1$

or $\left(\dfrac{N}{0.90 + N}\right) = 2.5\left(\dfrac{0.10 - N}{2.10 - N}\right)$

Solve for N because Elroy says so:

$$N(2.10 - N) = (2.5)(0.90 + N)(0.10 - N)$$

$$2.10N - N^2 = (2.5)(0.09 - 0.80N - N^2)$$

$$(2.50 - 1)N^2 + [2.10 + (2.5)(0.80)]N - (2.5)(0.09) = 0$$

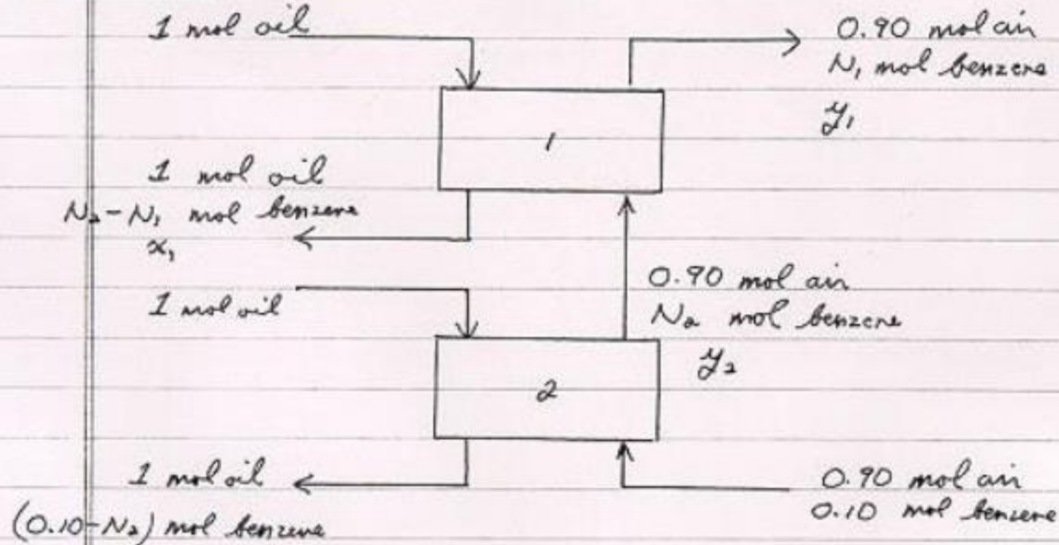
$$(1.50)N^2 + 4.10N^2 - 0.225 = 0$$

$$N = \frac{-4.10 \pm \sqrt{(4.10)^2 - 4(1.50)(-0.225)}}{2(1.50)} = 0.0538$$

(choose + root)

Then $y_1 = N/(0.9 + N) = \boxed{0.0564}$

scheme 2



lower stage

Exiting streams at equil. $\Rightarrow$ $y_2 = 2.5\, x_2$

$$\text{or} \quad \left(\frac{N_2}{0.90 + N_2}\right) = 2.5\left(\frac{0.10 - N_2}{1 + (0.10 - N_2)}\right)$$

Solve for N_2 as before $\Rightarrow$ $N_2 = 0.0702$

upper stage

Exiting streams at equil. $\Rightarrow$ $y_1 = 2.5\, x_1$

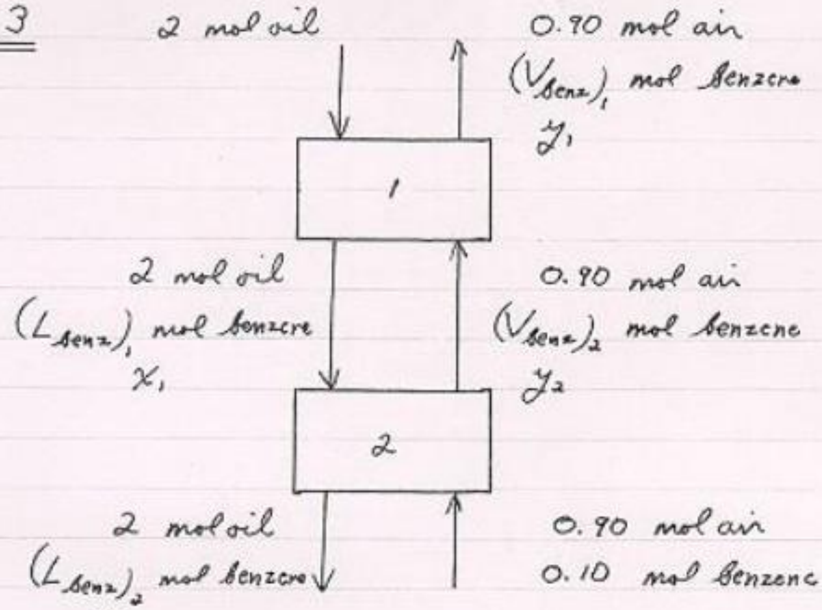
$$\text{or} \quad \left(\frac{N_1}{0.90 + N_1}\right) = 2.5\left(\frac{0.0702 - N_1}{1 + (0.0702 - N_1)}\right)$$

N_2 (now known!)

Solve for N_1 $\Rightarrow$ $N_1 = 0.0491$

Then $y_1 = N_1/(0.90 + N_1) =$ **0.0517** ← smaller, therefore better!

scheme 3



By benzene balances around stage 1 and stage 2:

$$(L_{benz})_1 + (V_{benz})_1 = 0 + (V_{benz})_2 \qquad (1)$$

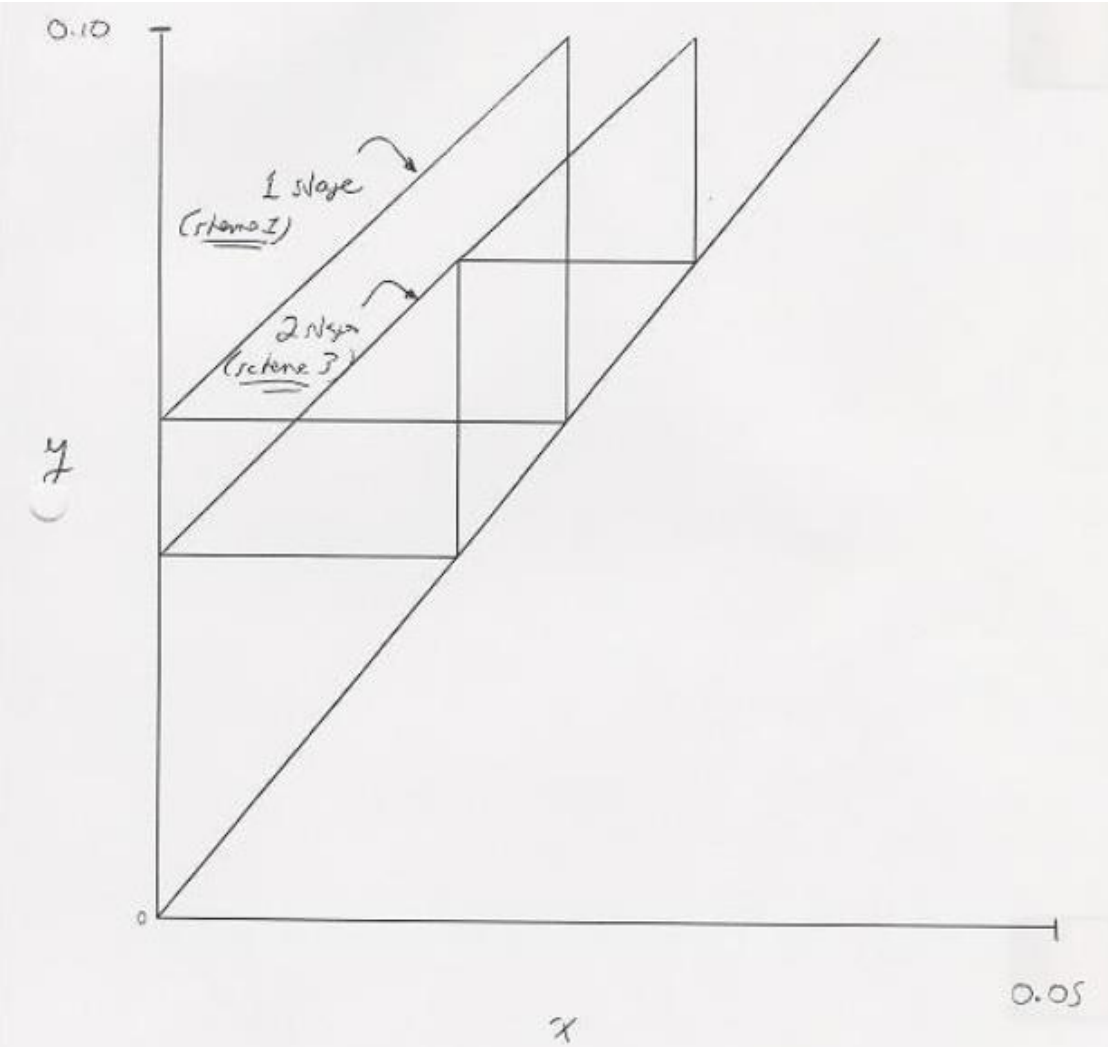
$$(L_{benz})_2 + (V_{benz})_2 = (L_{benz})_1 + 0.10 \qquad (2)$$

Equil relations for stages 1 and 2:

$$\underbrace{\left(\frac{(V_{benz})_1}{0.90 + (V_{benz})_1}\right)}_{y_1} = 2.5\underbrace{\left(\frac{(L_{benz})_1}{2 + (L_{benz})_1}\right)}_{x_1} \qquad (3)$$

$$\underbrace{\left(\frac{(V_{benz})_2}{0.90 + (V_{benz})_2}\right)}_{y_2} = 2.5\underbrace{\left(\frac{(L_{benz})_2}{2 + (L_{benz})_2}\right)}_{x_2} \qquad (4)$$

Can write $(L_{benz})_1$ and $(L_{benz})_2$ in terms of $(V_{benz})_1$ and $(V_{benz})_2$ wherever they appear in (3) and (4) using material balance relations (1) and (2):



$(L_{benz})_1$

$$\left(\frac{(V_{benz})_1}{0.90 + (V_{benz})_1}\right) = 2.5\left(\frac{(V_{benz})_2 - (V_{benz})_1}{2 + (V_{benz})_2 - (V_{benz})_1}\right) \quad (5)$$

$$\left(\frac{(V_{benz})_2}{0.90 + (V_{benz})_2}\right) = 2.5\left(\frac{0.10 - (V_{benz})_1}{2 + 0.10 - (V_{benz})_1}\right) \quad (6)$$

[Note: by adding eqs. (1) and (2) or by overall benzene balance, $(L_{benz})_2 = 0.10 - (V_{benz})_1$.]

Have 2 eqs. (5) and (6) in the 2 unknowns $(V_{benz})_1$ and $(V_{benz})_2$.

MatLab Code to solve these equations:

```
> # The two unknowns are Vbenz1 and Vbenz2
  #
  # Equation (5) can be written as f1(Vbenz1,vBenz2) = 0,
  # where f1(Vbenz1,Vbenz2) is the function
  #
  f1 := (Vbenz1,Vbenz2) -> Vbenz1 / (0.9 + Vbenz1)
          - 2.5 * (Vbenz2 - Vbenz1) / (2 + Vbenz2 - Vbenz1):
  #
  # Equation (6) can be written as f2(Vbenz1,vBenz2) = 0,
  # where f2(Vbenz1,Vbenz2) is the function
  #
  f2 := (Vbenz1,Vbenz2) -> Vbenz2 / (0.9 + Vbenz2)
          - 2.5 * (0.1 - Vbenz1) / (2 + 0.1 - Vbenz1):
  #
  # Solve the two equations simultaneously for the two
  # unknowns
  #
  fsolve({f1(Vbenz1,Vbenz2) = 0, f2(Vbenz1,Vbenz2) = 0},
          {Vbenz1, Vbenz2},
          {Vbenz1 = 0..0.1, Vbenz2 = 0..0.1});
  #
  # What fun!
  #
                {Vbenz1 = .03871656720, Vbenz2 = .07226536409}
>
```