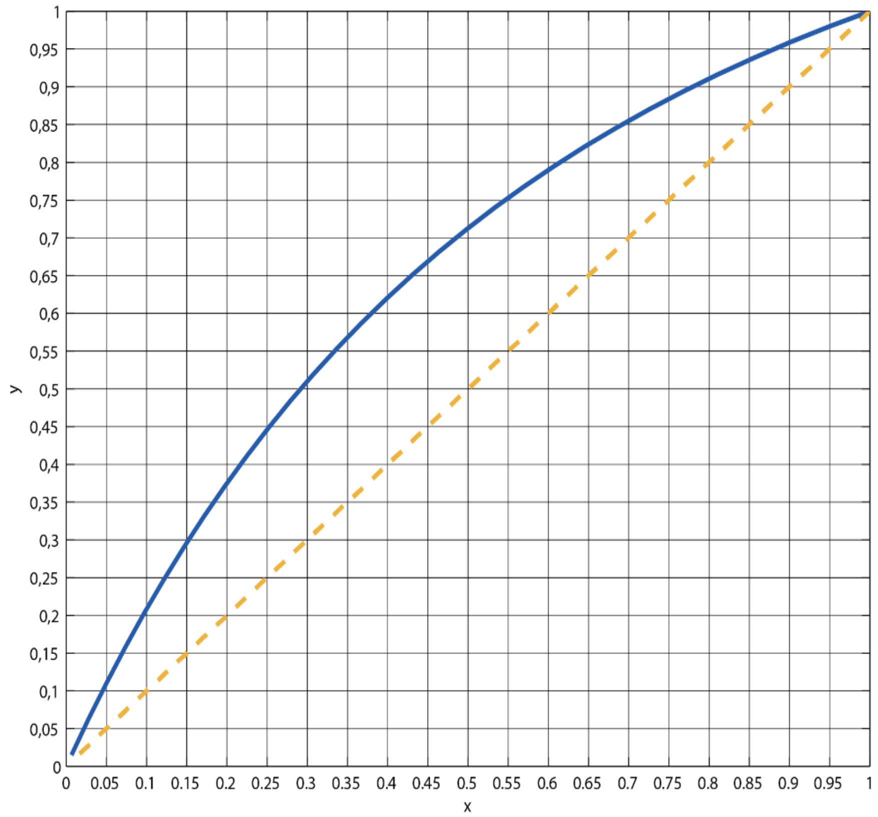
2019 Sep-Tek Exam problems

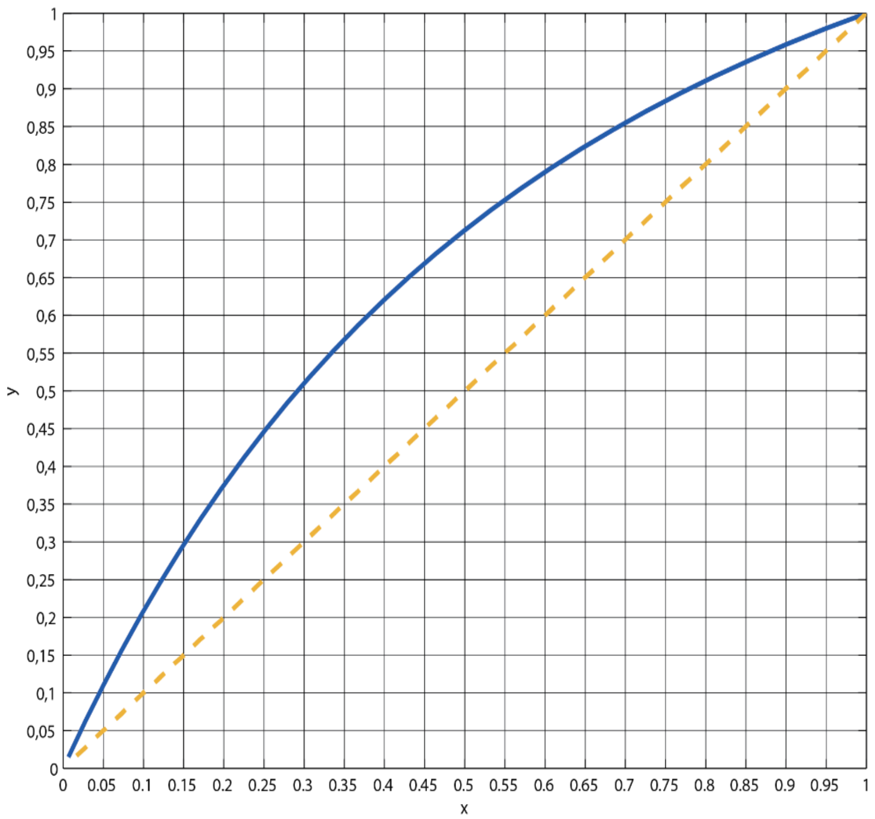
Problem 3: Distillation (30%)

A mixture of 35 mol% benzene and 65 mol% toluene is separated in a distillation tower at atmospheric conditions. The feed is a saturated liquid. The feed flow is 100 kmol/h. The distillate should be 95 mol% benzene (with a total condenser), while the bottom product (liquid) should be 90 mol% of toluene. The x-y diagram of the benzene-toluene system is given in the attachment 1. Please:

a) Draw a process flow diagram including the product flows (D, B) and internal flows (L_T, V_T, L_B, V_B). (3%)
b) Determine D and B in the process. (3%)
c) Find graphically the minimum number of equilibrium stages (Nmin). (2%)
d) Find the minimum reflux (Rmin). (4%)
e) Use the McCabe–Thiele method to determine the number of equilibrium stages N and determine the optimal feed-stage location (R=1.4Rmin). (10%)
f) Compute the required energy consumption (ΔH_{Vap} for benzene and toluene are 34 kJ/mol and 38 kJ/mol, respectively). (8%)

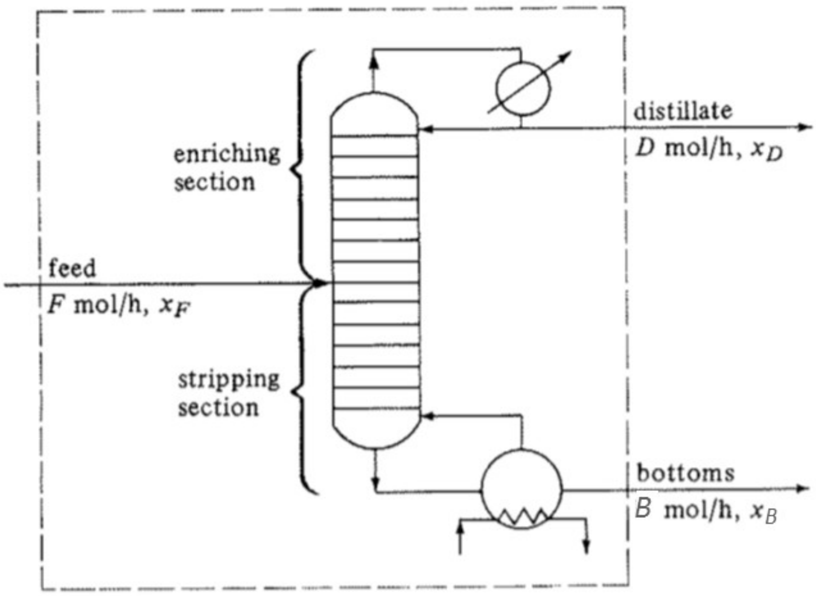
Attachment 1. Equilibrium diagram of the benzene-toluene system at 1 atm.





Solution 3:

a) The flow chart includes the condenser, reboiler and the flows **(3 p)**



b) Make material balance overall and component:

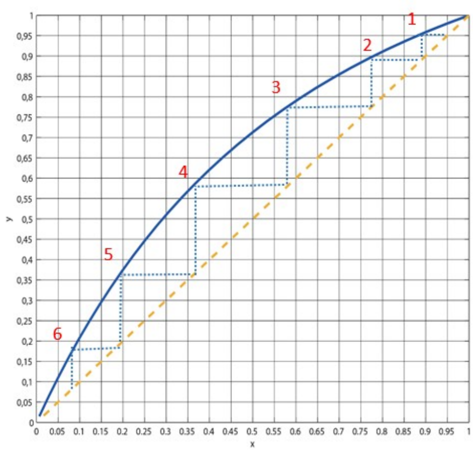
F=D+B =100 (1)

$Fx_F = Dx_D + Bx_B \rightarrow 100\times0.35 = D\times0.95 + B\times0.1$ (2)

Combine (1) and (2) → D= 29.4 [kmol/h]

B=70.6 [kmol/h] **(3p)**

c) Nmin **(2p)**



d) Determine Rmin

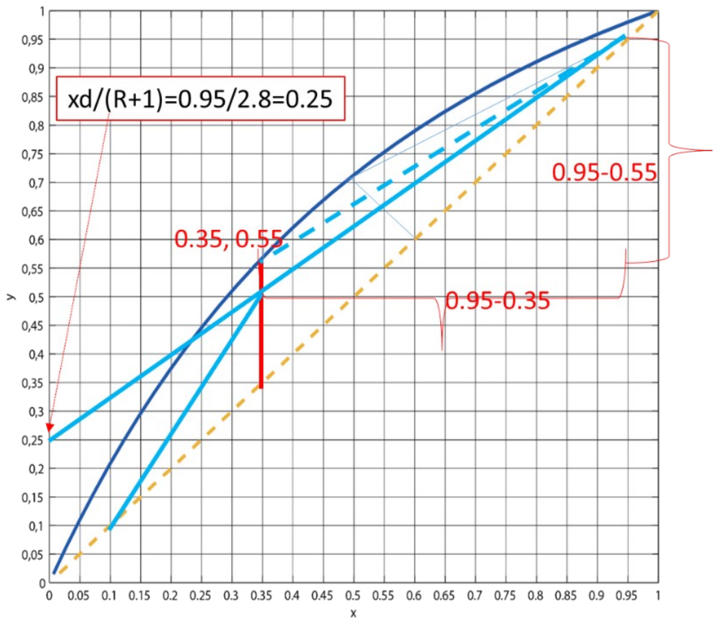
R=1.4×Rmin

Make the q-line: slope--> vertical

Find the cross point at the x-y curve (0.35,0.55) (if the data are +/-0.02 is acceptable)

Slope = Rmin/(Rmin+1) = (0.95-0.55)/(0.95-0.35) → Rmin =2 **(4p)**

(if the data are +/-0.1 is acceptable)



Rmin/(Rmin+1)=0.4/0.6 → Rmin=2 → R=2.8

e) <u>Find the reflux</u>:

R=1.4×Rmin=2.8 (if the data are +/-0.1 is acceptable) **(2p)**

<u>Draw operating lines</u>:

q-line **(2p)**

<u>Top operating line</u>:

Using slope = R/(R+1) = 2.8/3.8=0.737, draw a straight line starting from (0.95,0.95), or connect this point with the intercept at y axis (0.25,0), where x= x_D/(R+1) =0.95/(1+2.8)=0.25 **(2p)**

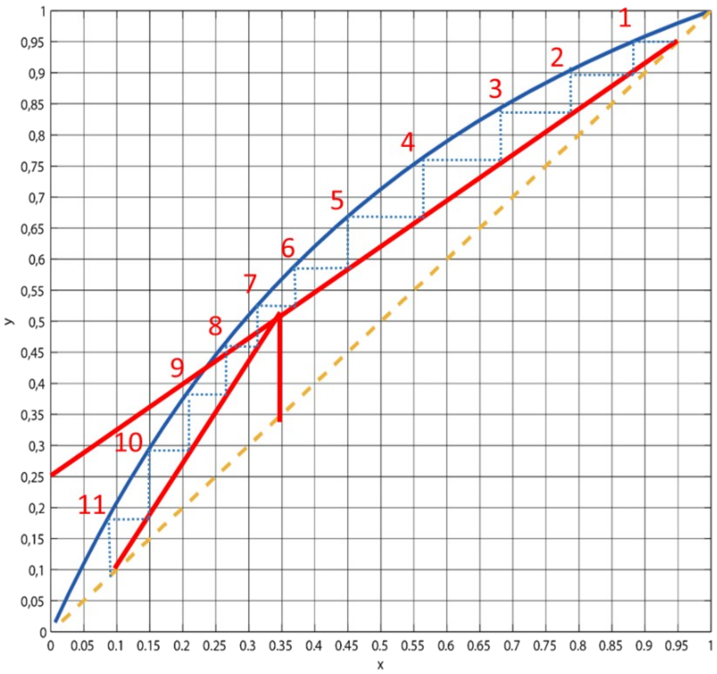
<u>Bottom operating line</u>:

Connect (xB, xB) and cross of the top operating line at the q-line **(2p)**

<u>Make the stairs:</u> **(2p).**

N= 11 No. 7 steps over the cross of the operating lines.

Thus, the feed stage is at No. 7 from the top, and the number of equilibrium stages N is 11 including the reboiler.



f) L_T=D×R=29.4 ×2.8 =82.32 [kmol/h] **(1p)**

V_T=L_T+D= 82.32+29.4 =111.72 [kmol/h] **(1p)**

L_B=L_T+ F= 82.32+100=182.32 [kmol/h] **(1p)**

V_B=VT= 182.32 -70.6=111.72 [kmol/h] **(1p)**

yB= 0.21 (xB=0.1 at x-y diagram)

ΔHBmix = 0.21×34+0.79×38=37.16 kJ/mol **(1p)**

ΔHDmix = 0.95×34+0.05×38= 34.2 kJ/mol **(1p)**

Q_B = V_B ×ΔHBvap = 111.72×(1000/3600) × ΔHBmix J/s

(still 2p if the ΔHBvap data were the data for pure toluene,

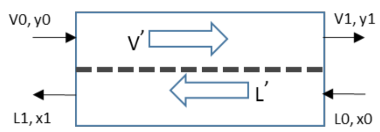
= 1153.2kJ/s = 1.15 MW) **(1p)**

Qc = V_T ·ΔHDvap = 111.72× (1000/3600) ×ΔHDmix×1000 J/s (still 2p if the ΔHBvap data were the data for pure benzene

1061.34 J/s = 1.06 (MW) **(1p)**

Problem 4: Absorption (10%)

A membrane contactor is used to absorb a small amount of A from a mixture of A+B (assume 2 mol% A in B), in which 98% of A is required to be absorbed. The feed gas flow is 300 kmol/h, at 30ºC, 1atm. Clean water (L=250 kmol/h) is used as the absorbent in a countercurrent flow. The gas-liquid equilibrium relationship for the A in water can be described by y=0.6x at 30ºC, 1atm.



a) Calculate the molar flows and compositions of the gas and liquid outlets. (4%)
b) Determine the minimum flow of the liquid (Lmin). (4%)
c) State the advantages and disadvantages of using membrane contactor as an absorber. (4%)

Solution 4: Reasonable errors in calculation are acceptable.

a) Determine the unknown parameters in the flow sheet. (V1, y1), (L_1) and (x_1). **(4p)**

Known: y_0=0.02, x_0=0, V_0=300, L_0=250 =L'

So: V'=V_0(1-y0) =300×0.98= 294 kmol/h

A inlet =V0 (y_0) = 300×0.02= 6 kmol/h

A outlet = (1-0.98)×A inlet = 0.12 kmol/h

V1=V'+Aoutlet =294+0.12= 294.12 kmol/h

y1= A outlet/V1 = 0.12/(294.12) = 0.00041

A absorbed: La=0.98×A inlet = 5.88

L_1= L'+La =250+5.88=255.88

X_1 = La/L_1 =5.88/250 = 0.0235

b) Minimum flow of the liquid L_{min} **(4p)**

$L_{min}(x^*_1) - L_{min}'x0 = 0.98\times y_0 V_0$

$x^*_1 = y_0/0.6 = 0.02/0.6 = 0.0333$

$L_{min} = 0.02\times0.98\times300/(0.02/0.6) = 176.4$ kmol/h

Lmin'= Lmin(1-x*)=170.52 kmol/h

Or by using the operating line method.

c) Advantages: **(4p)**

(4p for all, but 1p for each point given)

- Non-dispersive contact (no flooding, foaming or entrainment),
- High interfacial area
- Solvent hold up can be low
- Predictable performance
- Easy, linear scaling-up

Disadvantages:

- Extra mass transfer resistance from the membrane
- Membrane long term stability issue
- Sensitive pressure control: wetting/bubbling/solvent evaporation