Solution 1: Flash and distillation (20%)

1000 kmol/h mixture of equimolar benzene and toluene is to be separated in a single-stage flash at 1 atm. The equilibrium data for the benzene-toluene system at 1 atm is given in the table below. Coordinate papers are available in the attachment if needed.

TABLE 11.1-1. *Vapor-Pressure and Equilibrium-Mole-Fraction Data for Benzene–Toluene System*

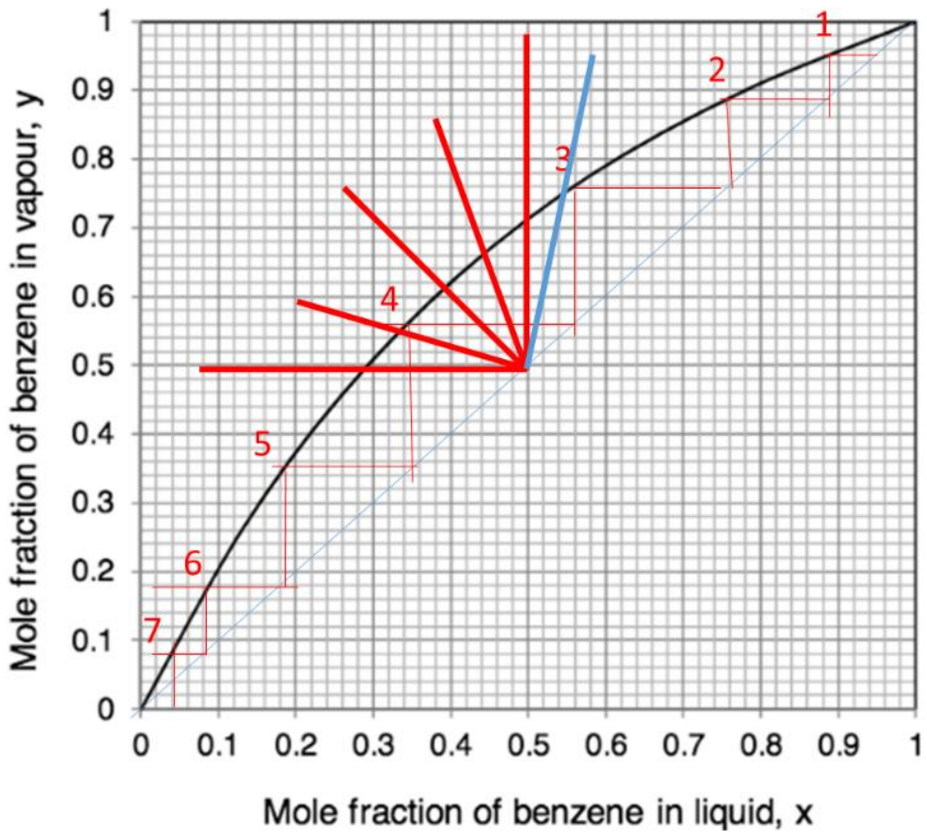
Temperature		*Vapor Pressure* Benzene		*Vapor Pressure* Toluene		*Mole Fraction Benzene at 101.325 kPa*	
K	*°C*	*kPa*	*mm Hg*	*kPa*	*mm Hg*	x_A	y_A
353.3	80.1	101.32	760			1.000	1.000
358.2	85	116.9	877	46.0	345	0.780	0.900
363.2	90	135.5	1016	54.0	405	0.581	0.777
368.2	95	155.7	1168	63.3	475	0.411	0.632
373.2	100	179.2	1344	74.3	557	0.258	0.456
378.2	105	204.2	1532	86.0	645	0.130	0.261
383.8	110.6	240.0	1800	101.32	760	0	0

The mixture may be fed in under the following conditions:

(1) 0% vaporized (saturated liquid).
(2) 25% vaporized.
(3) 50% vaporized.
(4) 75% vaporized.
(5) Saturated vapor.

Note: considering some data are drawn from figures, it is acceptable to allow different data in the answers if the methods are correct.

a) Plot the feed lines for each case and discuss how the feed lines change if the feed is colder than the saturated liquid (3p)



The slop of the feed line will be >1 if the feed is colder than the saturated liquid.

b) Determine the compositions (in mole fraction benzene) of the liquid and vapor leaving the flash separator under the five given conditions. (3p)
Find the cross points of the VLE and feed lines, which give the compositions:
(1) $q=1$, → $x=0.5$, $y=0.71$
(2) $q=0.75$, $y=0.75/0.25x+1/0.25x_F=3x+2$ → $x=0.44$, $y= 0.66$
(3) $q=0.5$, → $x=0.39$, $y=0.61$
(4) $q=0.25$, $y=0.25/0.75x+1/0.75x_F=x/3+2/3$ → $x=0.33$, $y=0.55$
(5) $q=0$, → $x=0.29$, $y=0.5$

c) A distillation column with a total condenser is now planned to separate the same mixture for products of higher purity. The produced benzene purity is required to be 95%, and the benzene recovery is 95%. Is it possible for the separation if a column has 5 stages is used? (3p).
Draw stairs between the diagonal line and VLE line (figure above). The N_{min} is 7, so 6 stages are not sufficient.
Note: The process diagram is not required, but if it is given to show the composition, 1-2 points may be given depending on how correct the diagram is (total points not exceed).

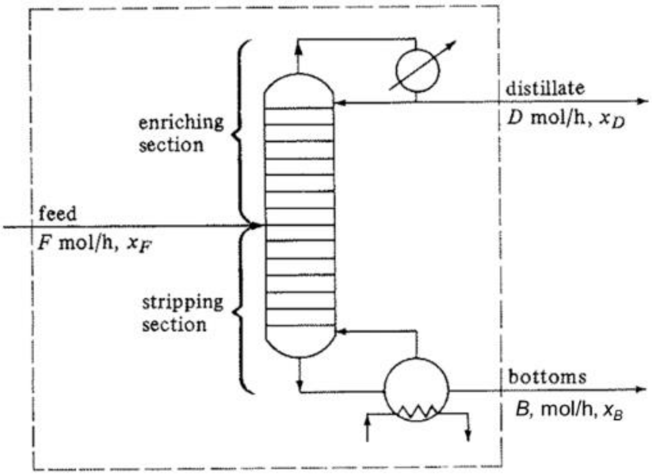


FIGURE 11.4-3. *Distillation column showing material-balance sections for McCabe–Thiele method.*

d) If 5 stages are not possible, make a new distillation column design that can fulfill the required separation. Take the 25% vaporized feed condition as an example and the reflux ratio (R) is set to be 3. Please provide the following key parameters for the design of the distillation column:

(1) the distillate and bottom product composition and flow rates (3p).

to make the recovery 95%, from F=D+B   1000=D+B

$Dx_D/Fx_F=0.95$ and $x_D=0.95$, D=500 and B=500

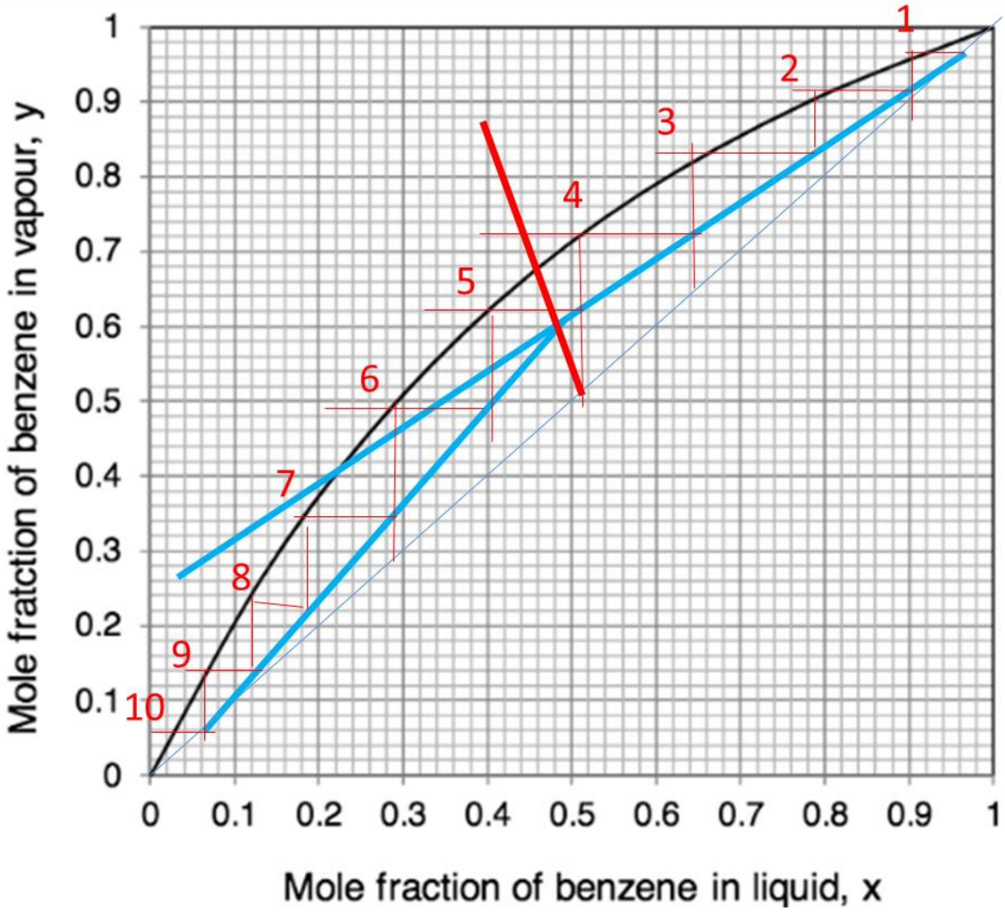
$Fx_F=Dx_D+Bx_B$ → $1000*0.5=500*0.95+500x_B$,

→ $x_B=0.05$

(2) the total number of equilibrium stages required (6p).

Draw operating lines and stairs. The slope of the feedline must be correct.

Stage 9 passes x_B, so 9 stages are required.



(3) the optimum feed plate location (2p).

The feed stages is at the 5rd from the top.

Solution 2: Absorption (20%)

A gas mixture stream (36 kmol/h) containing 4.0 mol% of ethyl alcohol. An absorption tower is used to recover 90% of the ethyl alcohol at 25ºC and 1bar. The equilibrium relationship for ethyl alcohol in water at 1bar follows y=0.6x. Coordinate papers are available in the attachment if needed.

a) If 18 kmol/h pure water is used as absorbent, is it possible to reach the required separation? (3p)

$V' = V_{in} \times (1-0.04) = 34.56$ kmol/h

$x^* = 0.04/0.6 = 0.067$

$y_{out} = V_{in} \times 0.04 \times 0.1/(V' + V_{in} \times 0.04 \times 0.1) = 0.0041$

$L_{min}/V = (y_{in} - y_{out})/x^* = 0.536$

If L=18 kmol/h, $L/V = 18/34.56 = 0.521 < L_{min}/V$

It is not possible to reach the separation.

(Note: other approaches can be used. Full points are given is the conclusion is correct)

What is the recovery rate the current process can reached? (3p)

When $L/V = 0.521 = (y_{in} - y_{out}')/x^*$ → $y_{out}' = 0.0051$

Assume the recovery rate is *R*. To get $y_{out} = 0.0051$,

$36 \times 0.04 \times (1-R)/[34.56 + 36 \times 0.04 \times (1-R)] = 0.0051$

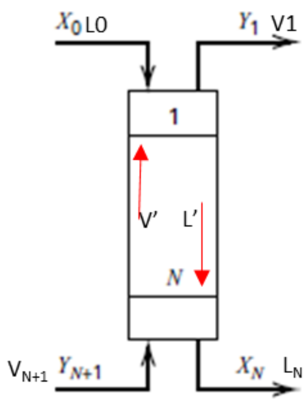
→ $R = 0.878$

(Note: other approaches can be used. Full points are given is the method is correct)

b) If the recovery rate cannot reach 90% as required, what changes should be made to fulfill the separation requirement? Assume the L is 2 time of L_{min}.

(1) Draw a process diagram of your design with flow variables. (3p)

Draw a process diagram with flow variables



Explain the change you decide to make (2p)

The L/V ratio must be increased.

$L/V = 2 \times 0.536 = 1.072$ → $L = V' \times 1.072 = 37.05$ kmol/h

(2) Determine the unknown parameters in the diagram for your design (e.g., V', L_{out} and V_{out}, y_{out} and x_{out}).(3p)

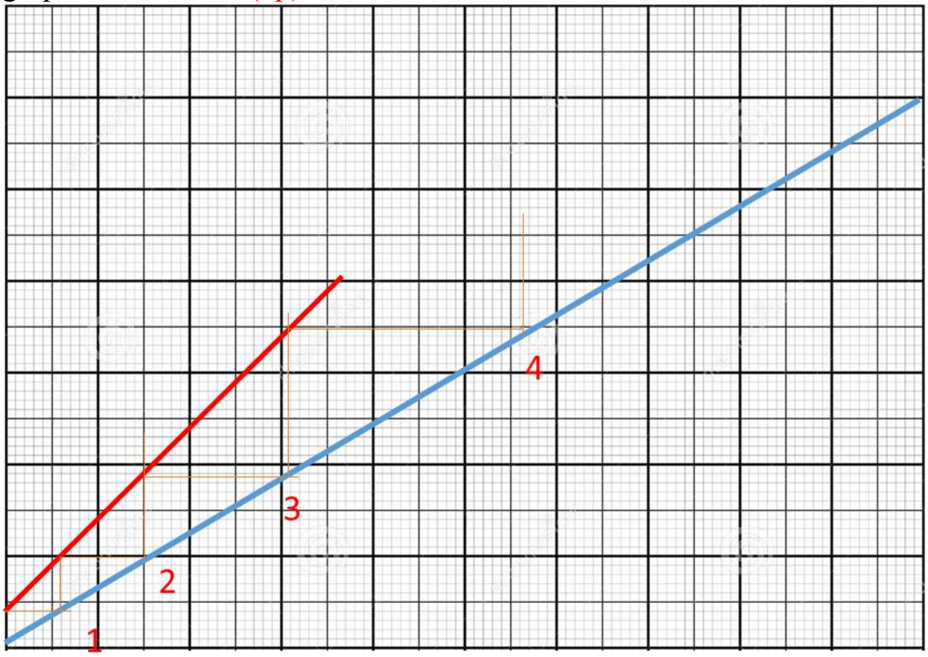
$y_{in} = 0.04$, $x_{in} = 0$, $y_{out} = 0.0041$ $V' = 34.56$

$L/V = 2 \times 0.536 = 1.072$

$L_{in} = V' \times 1.072 = 37.05$ kmol/h

$x_{out} = (y_{in} - y_{out}) \times (L/V) = (0.04 - 0.0041) \times 1.072 = 0.0385$

(3) Determine the number of stages required for this absorption column using a graphical solution. (3p)



3.2 stages, or 4 stages

(Note: if the equilibrium and operating lines are correct or the methods are correct but the data are wrong from the previous calculation, 1-2p will be given. The number of stages can be different due to the error of graphic solutions)

(4) What is the diameter of the column, given that the superficial gas velocity (neglecting the area taken by the packings and liquid) is 2 m/s. (3p)

V=36 kmol/h → Volume flow $V=22.4\times36/3600=0.224 m^3/s$

Standard volume flow $V_{P,,T}=0.224\times(T/T_0)\times(P_0/P)=0.224\times293/273*(1/1)=0.24\ m^3/s$

$3.14\times D^2/4 = V_{P,T}/v = 0.24/2$

→ D=0.39m