Binary distillation

Using a tray column, a binary mixture with components A and B has to be separated by distillation. The feed F with $x_{F,A}$ is a two phases stream with 50% vapor. It is separated into three parts:

- a distillate stream D with $y_{D,A}$ (vapor)
- a bottom stream B with $x_{B,A}$
- a side stream S with $y_{S,A}$. S is a saturated vapor.

The column is adiabatic and the molar evaporation enthalpies of A and B are identical.

Data:

F=100 kmol/h	$x_{F,A}$=0.4
S=21.5 kmol/h	$y_{S,A}$=0.79
Q_c=100 kW	$y_{P,A}$=0.96
Δh_v=8330 kJ/kmol	$x_{B,A}$=0.04

Δh_v = evaporation enthalpy of A and B at condensation temperatur.

Questions

a) Draw the process scheme.

b) Estimate the distillate stream D and the bottom stream B in kmol/h.

c) How large is the reflux ratio R at the top of the column?

d) At which stage is the side stream S withdrawn?

e) Define the equation of the operating line between feed stage and the stage where S is withdrawn, in the form $y_A = f(R, S, D, y_{S,A}, y_{D,A}, x_A)$

f) How many stages are needed to fulfil the separation task?

g) At which stage is the feed position f?

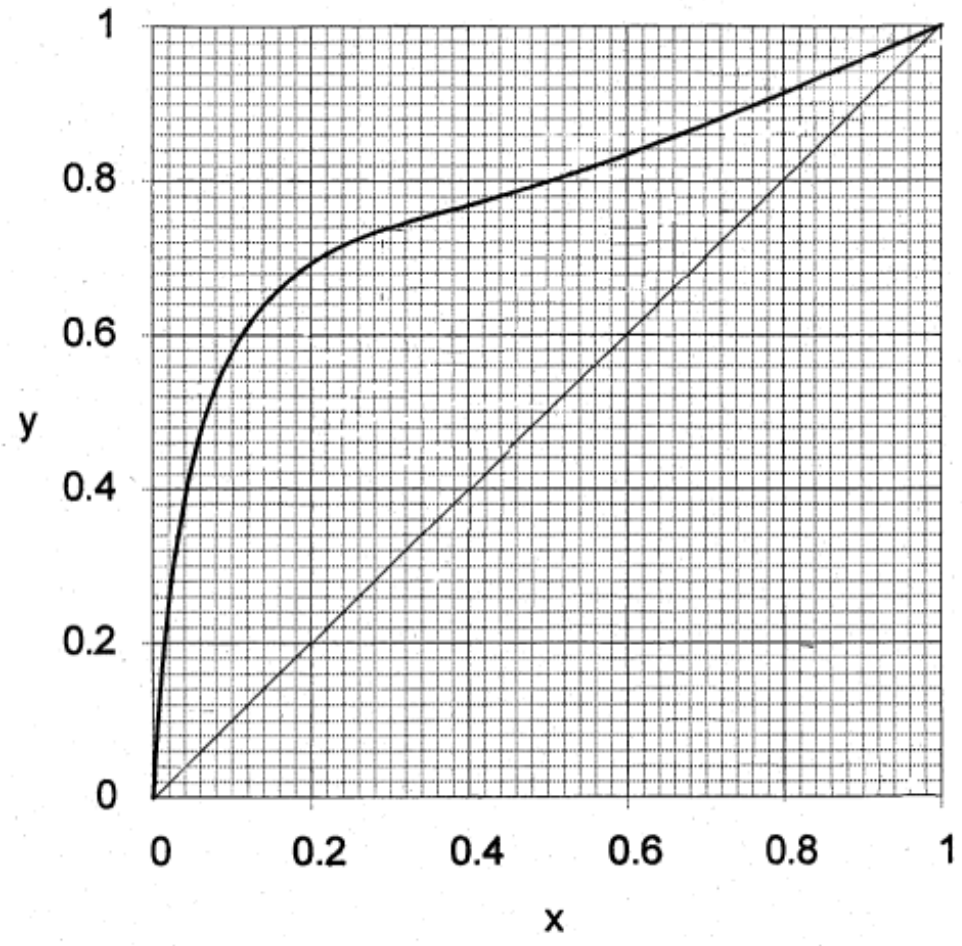

Figure 1: McCabe-Thiele diagram

Guideline for the solution

Question a)

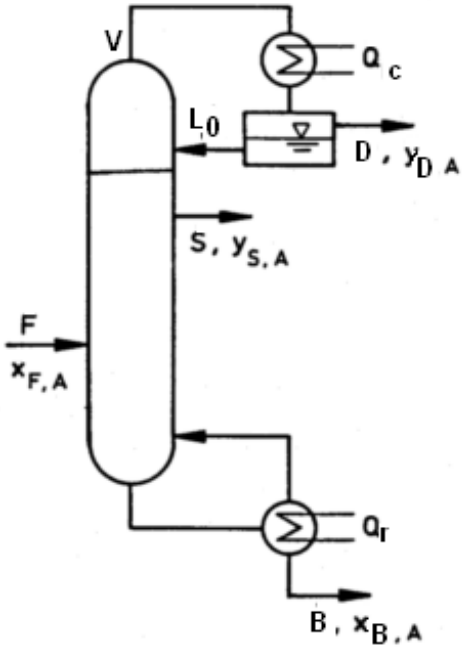

Figure 2: Process Scheme

Question b)

Distillate (D) and bottom (B) stream:

$$F = S + D + B \tag{1}$$

$$F \cdot x_F = S \cdot y_S + D \cdot y_D + B \cdot x_B \tag{2}$$

$$D = \frac{F \cdot (x_F - x_B) - S \cdot (y_S - x_B)}{y_D - x_B} = \frac{100kmol/h(0.4 - 0.04) - 21.5kmol/h(0.79 - 0.04)}{0.96 - 0.04} = 21.6kmol/h \tag{3}$$

with equation 1

$$B = 100kmol/h - 21.5kmol/h - 21.6kmol/h = 56.9kmol/h \tag{4}$$

Question c)

Reflux ratio:

$$Q_c = L_0 \cdot \Delta h_v \tag{5}$$

$$R = \frac{L_0}{D} \tag{6}$$

$$R = \frac{Q_c}{\Delta h_v \cdot D} = \frac{100kJ/s \cdot 3600s/h}{8330kJ/kmol \cdot 21.6kmol/h} = 2 \tag{7}$$

Question d)

Withdrawing side stream S:

Draw rectification line into the equilibrium diagram. Intersection point A with y-axis:

$$A = \frac{y_D}{1+D} = \frac{0.86}{3} = 0.32 \tag{8}$$

Step-by-step construction until y_S leads to a withdraw of side stream S from the third stage from the top of the column.

Question e)

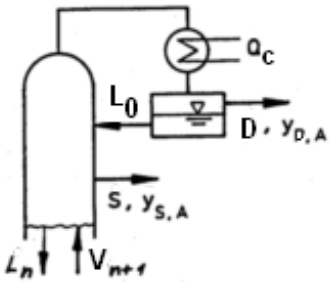

Figure 3: Process Scheme

$$V_{n+1} = S + L_n + D \tag{9}$$

$$V_{n-1} \cdot y_{n+1} = S \cdot y_{S,A} + L_n \cdot x_n + D \cdot y_{D,A} \tag{10}$$

$$y_{n+1} = \frac{S \cdot y_{S,A} + L_n \cdot x_n + D \cdot y_D}{S + L_n + D} \tag{11}$$

Since side stream S is withdrawn as a saturated vapor, L_n is equal D, and R=L_0/D. Using this in equation 11 gives

$$y_{n+1} = \frac{(S/D) \cdot y_S + R \cdot x_n + y_D}{(S/D) + R + 1} \tag{12}$$

Question f)

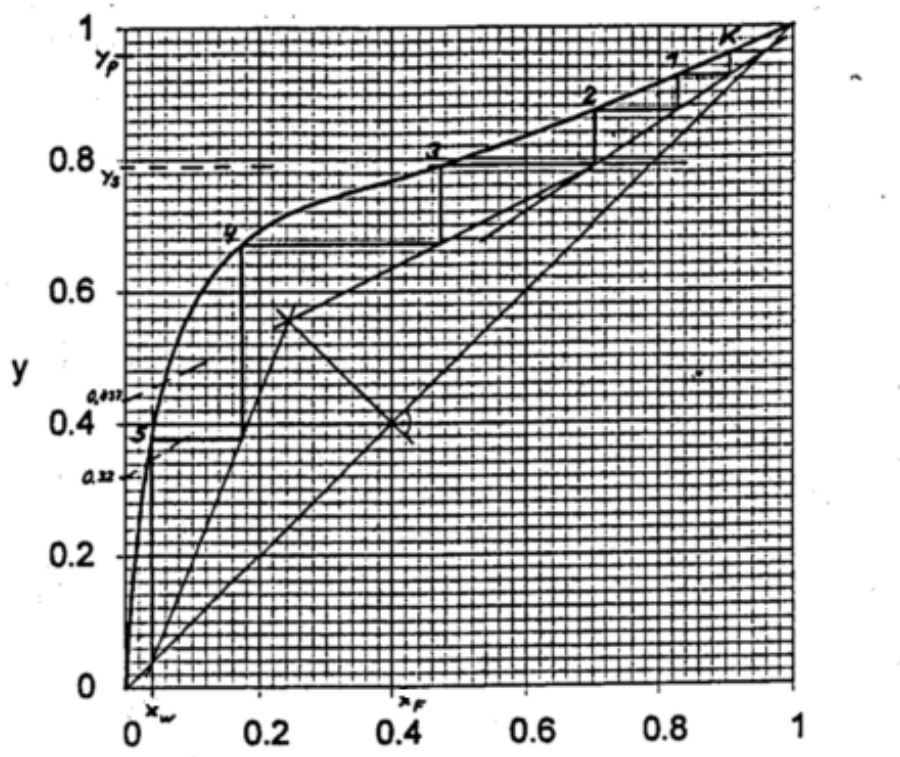

Figure 4: Graphical construction

Draw operating line into the McCabe-Thiele diagram, step-by-step construction leads to 6 theoretical stages

Question g)

Feed stream F is fed below stage 4 (see diagram 4)