Homework 1 solution

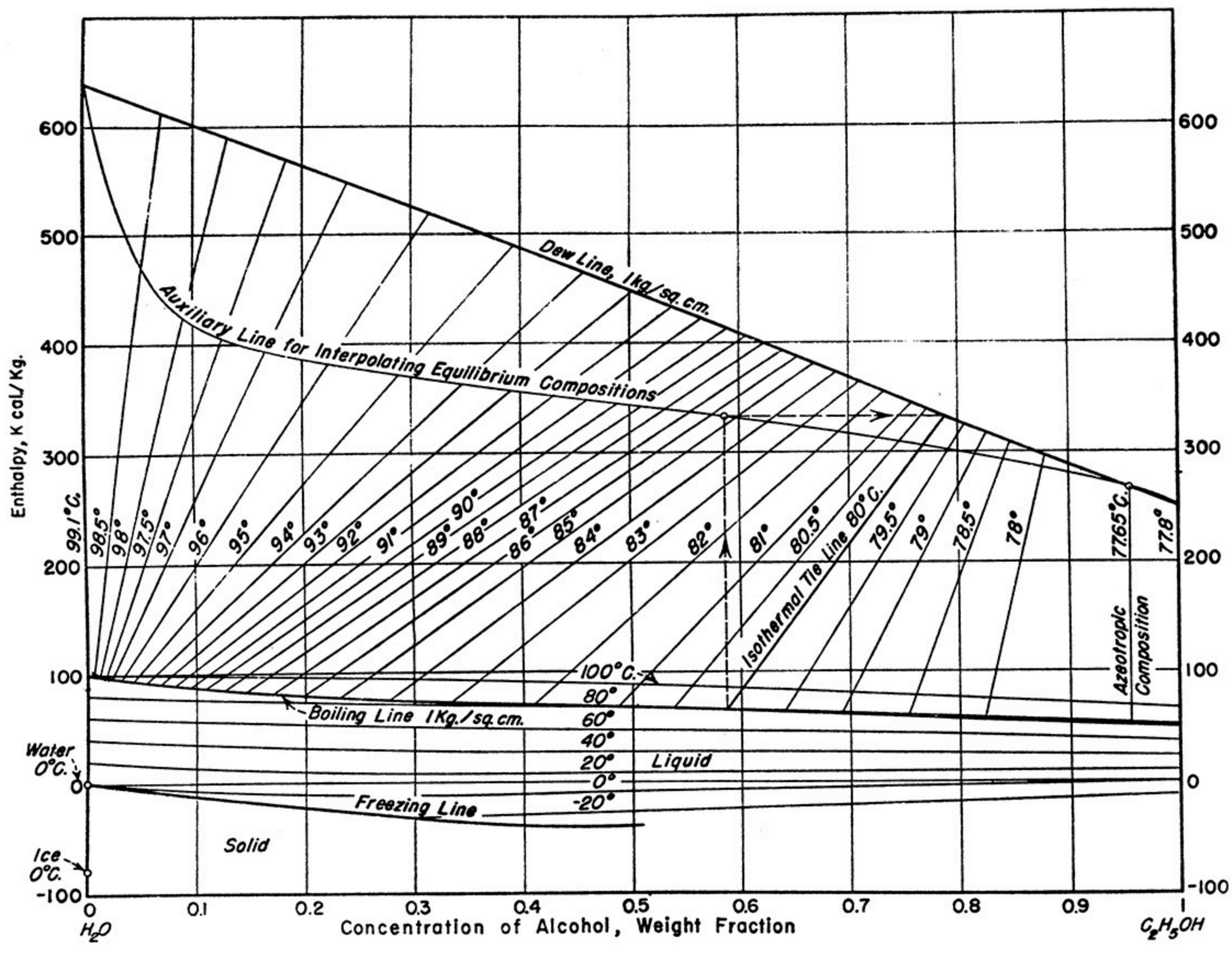
EPFL

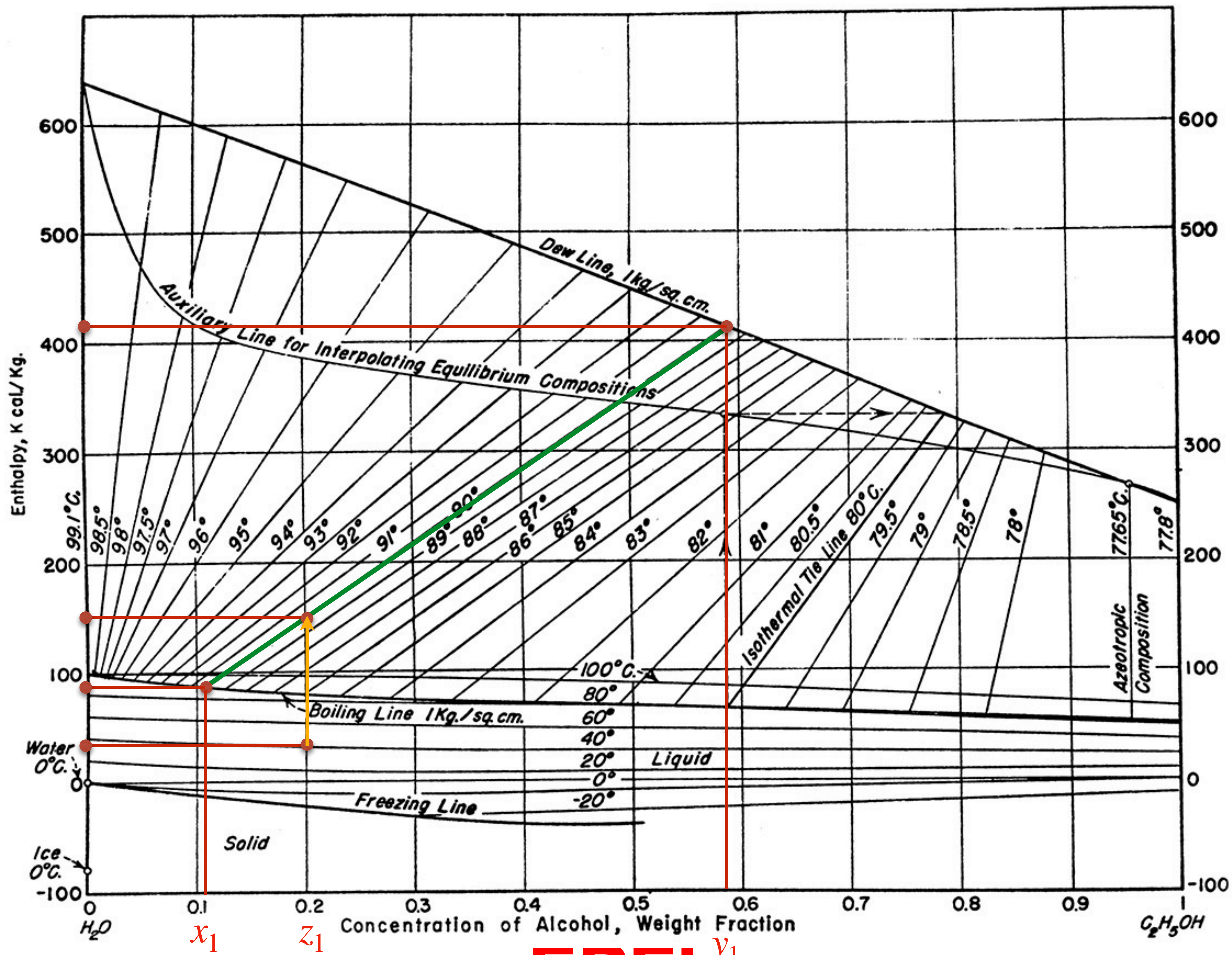
1) You need to upgrade 1000 kg ethanol-water liquid mixture containing 20 wt% ethanol available at 40 °C. You decided to heat the mixture in a closed vessel to 90 °C. Calculate

   a) The composition (in wt%) and amount (in kg) of resulting liquid and vapor phases. **(20 points)**

   b) The specific enthalpy (in kcal/kg) for the liquid and the vapor phases. **(20 points)**

   c) Minimum amount of energy (in kcal) that is required to reach 90 °C from 40 °C. **(20 points)**




Enthalpy, K cal/ Kg.
Dew Line, 1kg/sq.cm.
Auxiliary Line for Interpolating Equilibrium Compositions
Isothermal Tie Line 80°C.
Boiling Line 1Kg./sq.cm.
Freezing Line
Liquid
Solid
Water 0°C.
Ice 0°C.
Azeotropic Composition
77.65°C.
77.8°
Concentration of Alcohol, Weight Fraction
H_2O
C_2H_5OH
x_1
z_1
y_1

EPFL

① From the plot,

feed composition $(z_1) = 0.4$

After phase change, liquid phase has $x_1 = 0.11$

⇒ 11 wt.% ethanol, 89.% water

vapor phase has ~~ø~~ $y_1 = 0.58$

⇒ 58% ethanol and 42% water

Amount of liquid is obtained from the lever rule

$$= \frac{89}{110} \times 1000 = 809 \text{ kg}$$

Note:- 89 and 110 is measured using a ruler.

Amount of vapor $= 1000 - 809 = 191$ kg

② Specific enthalpy can be obtained by directly reading from the graph paper

liquid phase ~ 85 kcal/kg, vapor phase ~ 415 kcal/kg

③ Minimum amount of energy is enthalpy change

Feed enthalpy ~ 35 Kcal/kg

Energy ~~needed~~ needed $= (809 \times 85) + (191 \times 415) - (35 \times 1000)$

$= 113030$ Kcal

2) Consider the separation of a binary two-phase mixture feed (with equal liquid and vapor in the feed) with constant relative volatility of 5 and z = 0.4 using equilibrium-stage distillation column with partial reboiler and total condenser. Feed flow rate is 100 liter/hr. Distillate and bottom purity requirements are 95 and 5%, respectively.

a) Calculate the minimum reflux ratio and minimum number of stages. (**20 points**)

b) Calculate the number of equilibrium stages including partial reboiler which is needed if you decide to operate with R = 1.5 Rmin. (**20 points**)

c) Calculate the resulting flow rates of distillate, bottom, vapor and liquid flows in the enriching section and vapor and liquid flows in the stripping section. (**10 points**)

d) Calculate boilup ratio **(5 point).**

e) How many equilibrium stages will be needed if you decide to use total reboiler (**5 points**).

EPFL

Solution

1) First, draw the equilibrium line using

$$y_1 = \frac{\alpha_{12} x_1}{(1 - x_1 + \alpha_{12} x_1)} \qquad \text{where } \alpha_{12} = 5$$

see the line on the graph sheet

Feed quality :- Equal vapor and liquid in feed
⇒ quality = 0.5

① Slope for R_{min} operating line = $\frac{0.95 - 0.58}{0.95 - 0.22} = 0.51$

$\Rightarrow \frac{R_{min}}{R_{min}+1} = 0.51$ $\Rightarrow R_{min} = 0.51 R_{min} + 0.51$
$\Rightarrow 0.49 R_{min} = 0.51$
$\Rightarrow R_{min} = 1.04$

minimum # of stages = 4 (see graph)

② When $R = 1.5 R_{min}$; $R = 1.56$

slope = $\frac{R}{R+1} = 0.61$

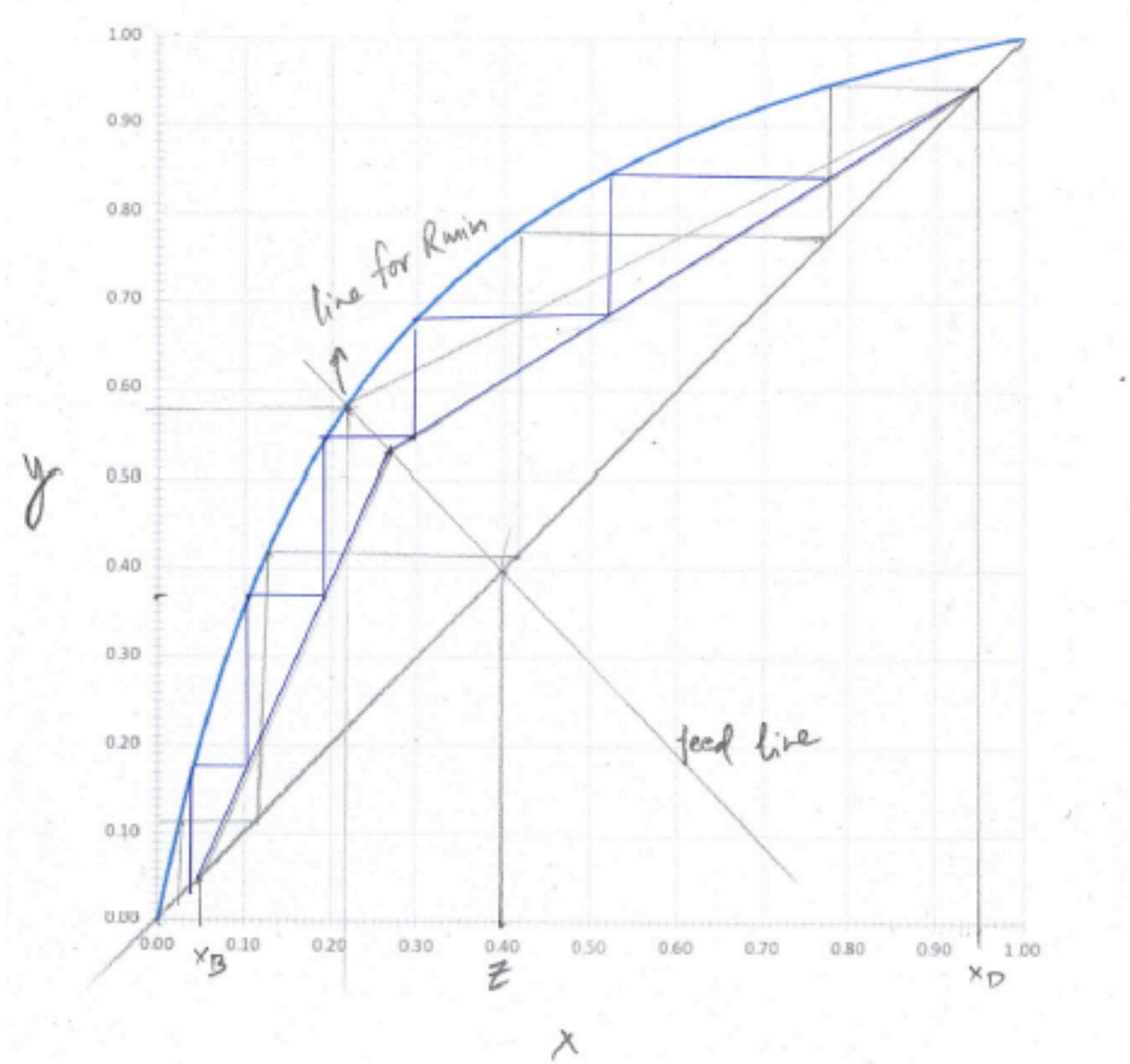
operating line $y = 0.61x + c$ crosses (x_D, x_D) $(0.95, 0.95)$

$0.95 = 0.61 \times 0.95 + c \Rightarrow c = 0.37$

$\Rightarrow y = 0.61x + 0.37$

Number of Stages = 6 (including partial reboiler)

Actual # of plates in column = 5



$D + B = F = 100$

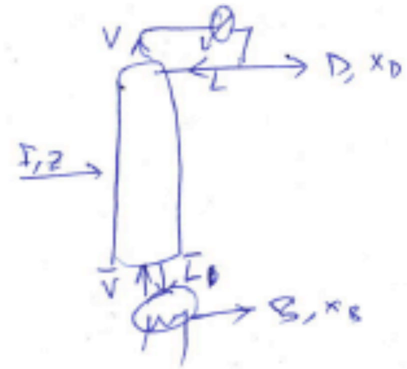
$0.95D + 0.05B = 0.4F = 40$

$0.95D + 0.95B = 95$

$0.9B = 55$

$\Rightarrow B = 57.9$ liter/h

$\Rightarrow D = 100 - 57.9 = 42.1$ liter/h



Enriching section

$R = \frac{L}{D} \Rightarrow L = RD = 42.1 \times 1.56 = 65.7$ liter/h

$V = L + D = 107.8$ liter/h

stripping section

~~q = 0.45~~ $q = 0.5 = \frac{\bar{L} - L}{F} \Rightarrow \bar{L} = L + qF$

$\Rightarrow \bar{L} = 65.7 + 0.5 \times 100$

$= 115.7$ liter/h

$q = 1 - \frac{V - \bar{V}}{F} \Rightarrow qF = F - V + \bar{V}$

$\Rightarrow \bar{V} = V + qF - F = 107.8 + 50 - 100$

= ~~65.7~~ ~~55~~ ~~liter/h~~

$= 57.8$ liter/h

(4) If we use total reboiler, the last stage will not be reboiler.

See the graph # 2

total # of equilibrium stages = 6 ~~(with~~

= # of plates in column