Separation Processes and Process Calculations 2

Separation Processes

Tutorial 6

1) An ethanol-water mixture with 0.3 mole fraction ethanol is to be distilled at 1atm. into a distillate product of 0.82 mole fraction ethanol and a bottoms product of 0.04 mole fraction ethanol. There will be a total condenser at the top but, instead of a reboiler at the bottom, live steam will be fed into the base of the column to supply the necessary heat. The feed is 40 mole % vapour and 60 mole % liquid. An equilibrium curve for the ethanol-water system is provided (Fig 1)

   a) Derive an equation for the operating line in the stripping section.
   b) Find the minimum steam rate (in moles per mole of bottoms product) which would permit this separation. [0.311]
   c) Determine the number of stages required at twice the minimum steam rate. What reflux ratio does this correspond to? [10, 4.88]

2) An aqueous solution containing 0.2 mole fraction ethanol is to be fractionated at 1 atm. into a distillate of 0.8 mole fraction ethanol and a bottoms product of 0.03 mole fraction ethanol. 1.405 moles of saturated steam are required to evaporate each mole of feed. A column with 7 equivalent theoretical stages (including the reboiler) is available. What reflux ratio should be used? What is the maximum purity of distillate obtainable in a single column? An equilibrium curve for the ethanol-water system is provided (Fig 2). [9, 89% ethanol]

3) 100kmol/h of saturated liquid air (79% molar nitrogen, 21% molar oxygen) is to be distilled at 1 atm. to produce a distillate of 99 mole % nitrogen and a bottoms with 1 mole % nitrogen. Distillate is withdrawn as saturated liquid from a total condenser and bottoms as a saturated liquid from a partial reboiler.

   In addition, a side stream of 30 kmol/h of a sturated vapour containing 50 mole % oxygen is to withdrawn at an appropriate point on the column.

   The column reflux ratio is to be 0.667

   a) What quantities of distillate and bottoms are produced hourly? [64.6kmol/h, 5.4kmol/h]
   b) How many theoretical stages are required? [8 + reboiler]
   c) From which stage should the sidestream be withdrawn and where should the feed be introduced? [6,4]

4) Two mixtures of A and B are to be separated by distillation at constant pressure in a distillation column equiped with a total condenser and a total reboiler, operating at a reflux ratio of 1.5. For the chosen pressure the average relative volatility is $\alpha_{AB} = 4.0$

   The stream compositions are shown in the following table:

Stream	Flowrate	Mole fraction A	Mole fraction B
Feed 1	50 kmol/h	0.50	Saturated liquid
Feed 2	100 kmol/h	0.35	Saturated vapour
Distillate		0.90	Saturated liquid
Bottoms		0.05	Saturated liquid

The Murfree efficiency varies with the liquid composition as shown below:

Mole fraction A	0.05	0.20	0.40	0.60	0.80	0.90
	0.67	0.67	0.67	0.50	0.50	0.50

a) How many actual stages are required? [11]
b) At which stage is each feed introduced? [4,8]
c) What is the overall stage efficiency? [64%]

5)

a) Derive the Fenske equation for the minimum number of theoretical stages required for a given binary distillation:

$$N_{\min} = \frac{\log\left(\dfrac{x_D(1-x_B)}{x_B(1-x_D)}\right)}{\log \alpha} - 1$$

where x_D = mole fraction more volatile component in the distillate
x_B = mole fraction more volatile component in the bottoms
α = relative volatility of more volatile to less volatile component.

b) Calculate the number of theoretical stages, at total reflux, required to produce 98 mole % toluene and 98 mole % m-xylene from their mixtures. The volatility of toluene relative to m-xylene at these two concentrations may be taken to be 2.70 and 2.13 respectively. [8]

c) If the feed for the above separation is saturated liquid with 44 mole % toluene, estimate the minimum reflux ratio. [1.53]

N.B. The mole fraction, *y,* of more volatile component in the vapour phase, in equilibrium with mole fraction, *x*, in the liquid phase, is given in terms of relative volatility by:

$$y = \frac{\alpha x}{(1+(\alpha-1)x)}$$

as is easily derived from Raoult's law.

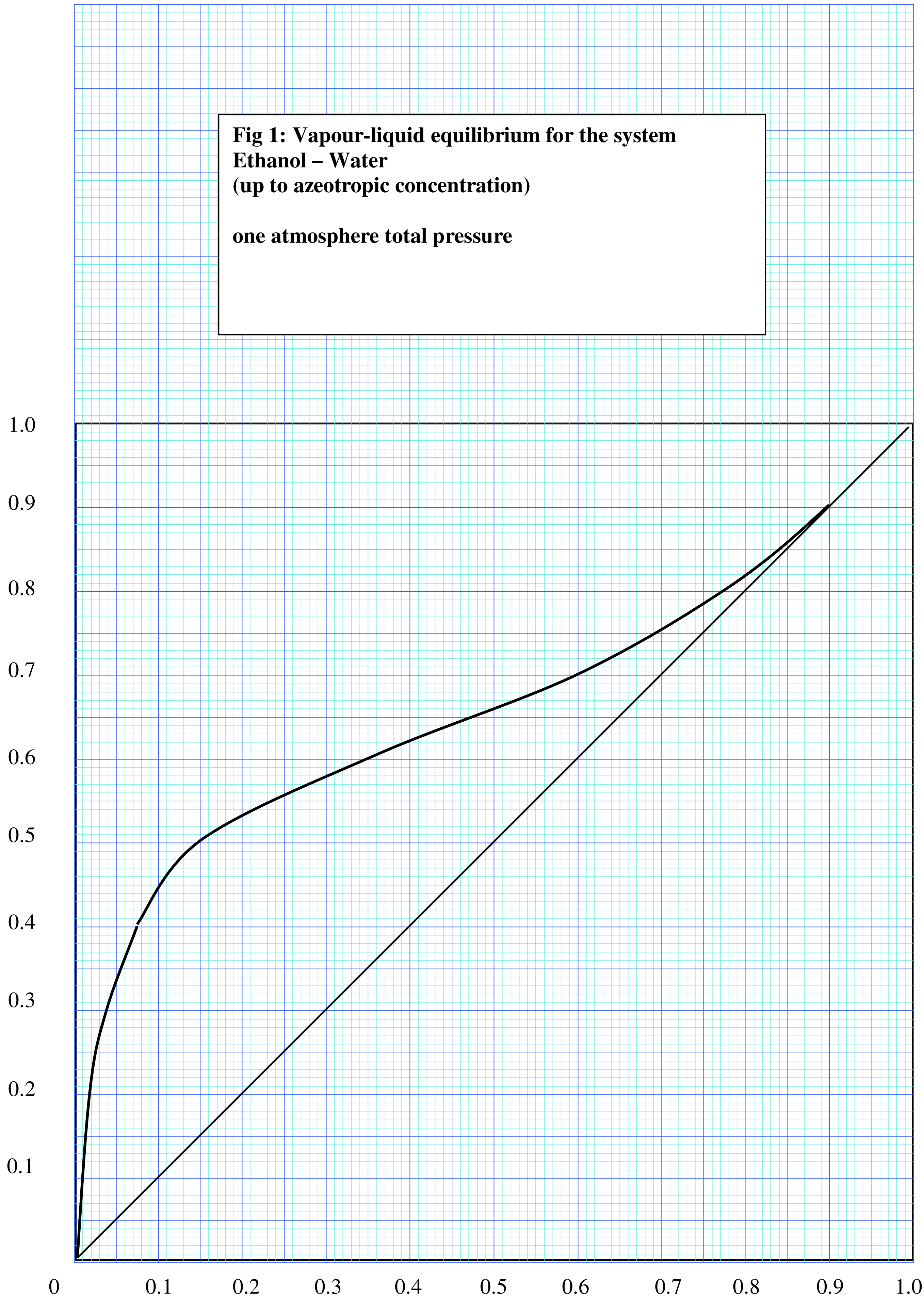
Fig 1: Vapour-liquid equilibrium for the system
Ethanol – Water
(up to azeotropic concentration)
one atmosphere total pressure
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

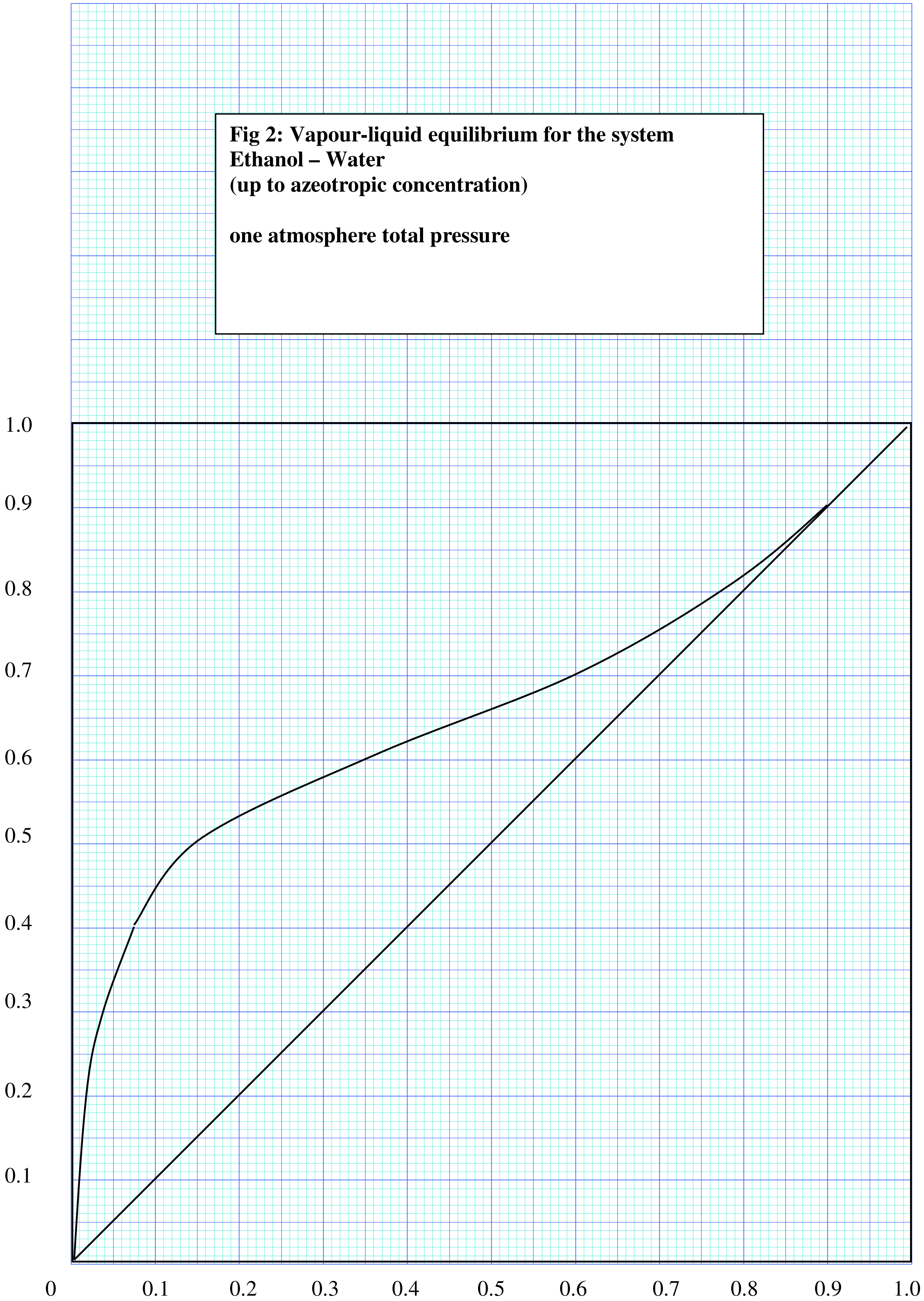
Fig 2: Vapour-liquid equilibrium for the system
Ethanol – Water
(up to azeotropic concentration)
one atmosphere total pressure
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Fig 3: Vapour-liquid equilibrium for the system Nitrogen-oxygen