UNIVERSITY OF ABERDEEN SESSION 2011–2012

Degree Examination in EG3570 Separation Processes

24th May 2012 2 pm – 5 pm

Notes: (i) *Candidates ARE permitted to use an approved calculator.*

(ii) *Candidates ARE permitted to use the Engineering Mathematics Handbook.*

(iii) *Candidates ARE permitted to use steam tables, which will be provided.*

(iv) *Data sheets are attached to the paper.*

PLEASE NOTE THE FOLLOWING

(i) You **must not** have in your possession any material other than that expressly permitted in the rules appropriate to this examination. Where this is permitted, such material **must not** be amended, annotated or modified in any way.

(ii) You **must not** have in your possession any material that could be determined as giving you an advantage in the examination.

(iii) You **must not** attempt to communicate with any candidate during the exam, either orally or by passing written material, or by showing material to another candidate, nor must you attempt to view another candidate's work.

Failure to comply with the above will be regarded as cheating and may lead to disciplinary action as indicated in the Academic Quality Handbook

(`www.abdn.ac.uk/registry/quality/appendix7x1.pdf`) **Section 4.14 and 5.**

Candidates must attempt *all* questions from PART A
AND *two* questions from *three* in PART B.

PART A: Answer ALL Questions

Question 1

In the production of sea salt, seawater is first evaporated to form a concentrated brine before then being passed to a crystallizer. The seawater feed to the evaporator can be modelled as a 4% w/w NaCL-water mixture and is available at a temperature of 9 °C. The brine must reach a concentration of 37% w/w NaCl before leaving the evaporator, otherwise the crystallizer will be unable to function.

a) An evaporator is needed to process 100 kg of sea salt per hour. Perform mass balances over the evaporator to determine the required flow rates of seawater, brine, and water vapour. [5 marks]

b) For maximum efficiency, the evaporator is operated at an absolute pressure of 0.48 bar. Calculate the operating temperature of the evaporator, stating any assumptions you make, and estimate the boiling point rise of the solution. You may need the Dühring data provided in Fig. 1. [5 marks]

c) Why is it convenient to talk in terms of a boiling point rise for mixtures at a certain concentration? [2 marks]

d) Calculate the duty of the evaporator using your steam tables. You may neglect the effect of NaCl concentration on the specific enthalpy. Comment on the superheat of the vapour. [5 marks]

e) Saturated steam is available at 1.5 bar, calculate the steam economy of the evaporator. [3 marks]

f) Calculate the heat transfer area required if the overall heat transfer coefficient is $U = 1600$ W/m^{2}K. [2 marks]

Question 2

a) Consider the VLE data for ethanol-water mixtures which are presented in Fig. 2.

   i) What VLE "feature" is present at high mole fractions of ethanol ($x_{ethanol} \approx 0.9$) and what difficulties will it present when trying to distill high purity ethanol from dilute feedstock? [3 marks]

   ii) Describe one method for how such a feature might be broken/overcome? [3 marks]

b) Using a mass balance, derive the following operating line equation for a flash drum.

$$y = (x_F - x\,q)\,/\,(1 - q)$$

where $q = L/F$ is the fraction of un-vapourised feed, x_F is the feed concentration, x is the outlet liquid concentration, and y is the outlet vapour concentration. [8 marks]

c) A flash drum, operating at 1 atm, is used to distill a 60 mole% ethanol and 40 mole% water mixture at a flow rate of 150 kmol/hr. The heat exchanger before the flash drum is set so that 80 mole% of the feed will vapourise in the drum. Graphically determine the outlet concentrations of the vapour and liquid streams using the VLE data for ethanol-water mixtures available in Fig. 3. [6 marks]

Note: If you draw on the VLE graph provided (Fig. 3), remember to include it in your exam booklet for marking.

Question 3

a) Derive the following operating line equation for the enriching section of a column using a mass balance.

$$y_n = \frac{R}{R+1} x_{n+1} + \frac{x_D}{R+1}$$

State any assumptions you make and discuss their range of validity. [10 marks]

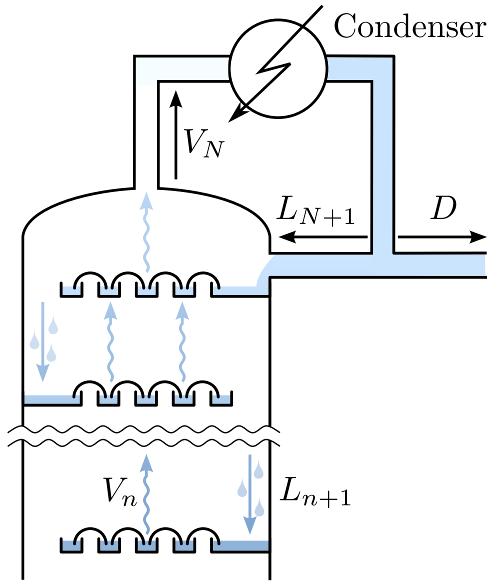

Figure: A diagram of the streams in the enrichment section of a distillation column.

b) Calculate the *minimum* number of ideal stages required in a distillation column to separate ethanol-water mixtures to a purity of 5 mole% bottoms and 60 mole% distillate. Why is the feed concentration unimportant in this limit? [8 marks]

Note: If you draw on the VLE graph provided (Fig. 3), remember to include it in your exam booklet for marking.

PART B: Answer TWO Questions From THREE

Question 4

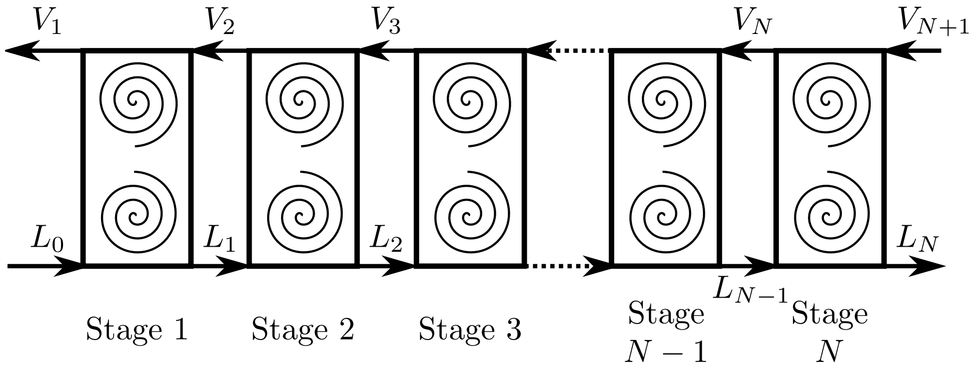

Figure: The stream numbering within a multi-stage absorber

A 30 kmol/hr gas stream produced from coal contains a light oil vapour (2 mole%) which is scrubbed out using an absorption column. The light oil vapour is washed out of the gas by contacting the gas with a 13 kmol/hr non-volatile heavy oil absorbent.

The heavy oil absorbent initially contains 0.005 mole% of absorbed light oil and it absorbs 90% of the light oil in the inlet gas. The equilibrium between the light oil vapour and the absorbed light oil is given by $y = 0.275\,x$. An X-Y diagram is provided in Fig. 4 and the HETP is 1.4 m/stage. Determine the height of packing required to carry out the specified absorption in a counter-current column. [20 marks]

Note: If you draw on the VLE graph provided (Fig. 4), remember to include it in your exam booklet for marking.

Question 5

a) Consider a simple batch still. Derive the following equation, known as Rayleigh's equation, for the concentration in the still.

$$\ln\left(\frac{L_{final}}{L_{initial}}\right) = \int_{x_{initial}}^{x_{final}} \frac{\mathrm{d}x}{y-x}$$

[10 marks]

b) For mixtures with an almost constant relative volatility, Rayleigh's equation may be solved to give

$$\ln\left(\frac{L_{final}}{L_{initial}}\right) = (\alpha-1)^{-1}\ln\left(\frac{x_{final}(1-x_{initial})}{x_{initial}(1-x_{final})}\right) + \ln\left(\frac{1-x_{initial}}{1-x_{final}}\right)$$

i) Define the relative volatility and describe the three cases, $\alpha > 1$, $\alpha = 1$, and $\alpha < 1$. [3 marks]

ii) A poteen producer wants to distill a 2.4 kmol mixture of ethanol (3.5 mole%) and water using Rayleigh distillation to produce a liqueur. Assuming an effective relative volatility of $\alpha \approx 7$, determine the concentration of the liqueur if 0.6 kmol of distillate is produced. [7 marks]

Question 6

A mixture of 40 mole% benzene and 60 mole% toluene is fed to a distillation column for purification. The bottoms product is specified at 10 mole% benzene and a minimum of 95 mole% benzene is required in the top product. 50 mole% of the feed flashes to vapour upon entering the column.

Note: If you use the VLE graph provided (Fig. 5), remember to include it in your exam booklet for marking.

a) Determine the minimum reflux ratio for this separation. [3 marks]

b) Calculate the number of theoretical stages required to perform the distillation at twice the minimum reflux ratio ($R = 2\,R_{min}$). [5 marks]

c) Calculate the number of real stages, using a Murphree tray efficiency of 0.5 below the feed and 0.75 above the feed. [10 marks]

d) Calculate and comment on the overall tray efficiency of the column. [2 marks]

END OF PAPER

DATASHEET

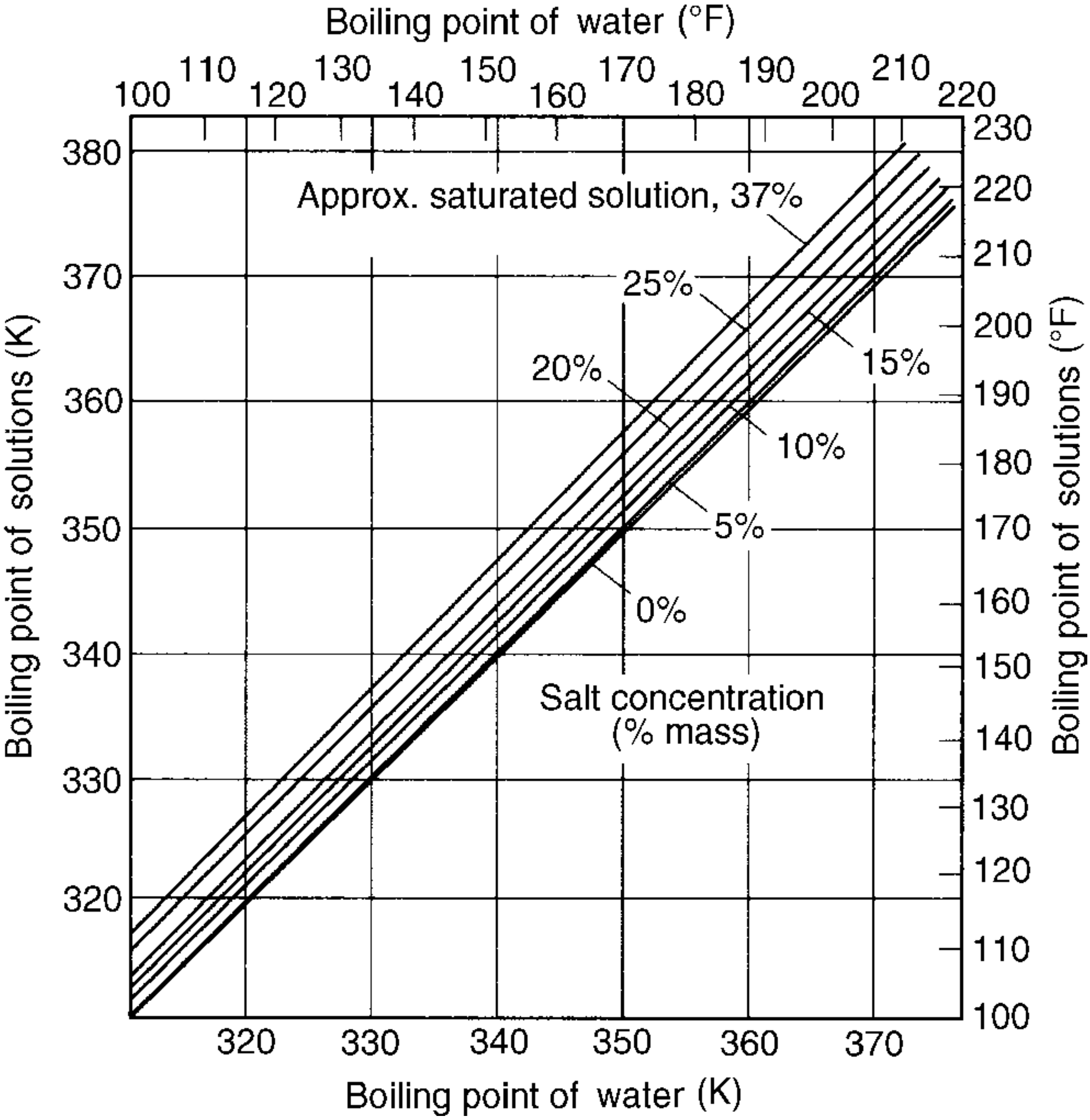

Figure 1: Dühring chart for NaCl solutions, taken from Fig. 14.1, pg. 772 C&R Vol. 2. This figure is needed for Q. 1b).

Operating lines:

$$y_n = x_{n+1}\frac{R}{R+1} + \frac{x_D}{R+1} \qquad \text{Enrichment line} \qquad (1)$$

$$y = x\frac{q}{q-1} - \frac{x_F}{q-1} \qquad q\text{-line} \qquad (2)$$

$$\frac{y_{A,n+1}}{1-y_{A,n+1}} = \frac{L'}{V'}\frac{x_{A,n}}{1-x_{A,n}} + \frac{y_{A,1}}{1-y_{A,1}} - \frac{L'}{V'}\frac{x_{A,0}}{1-x_{A,0}} \qquad \text{Absorption} \qquad (3)$$

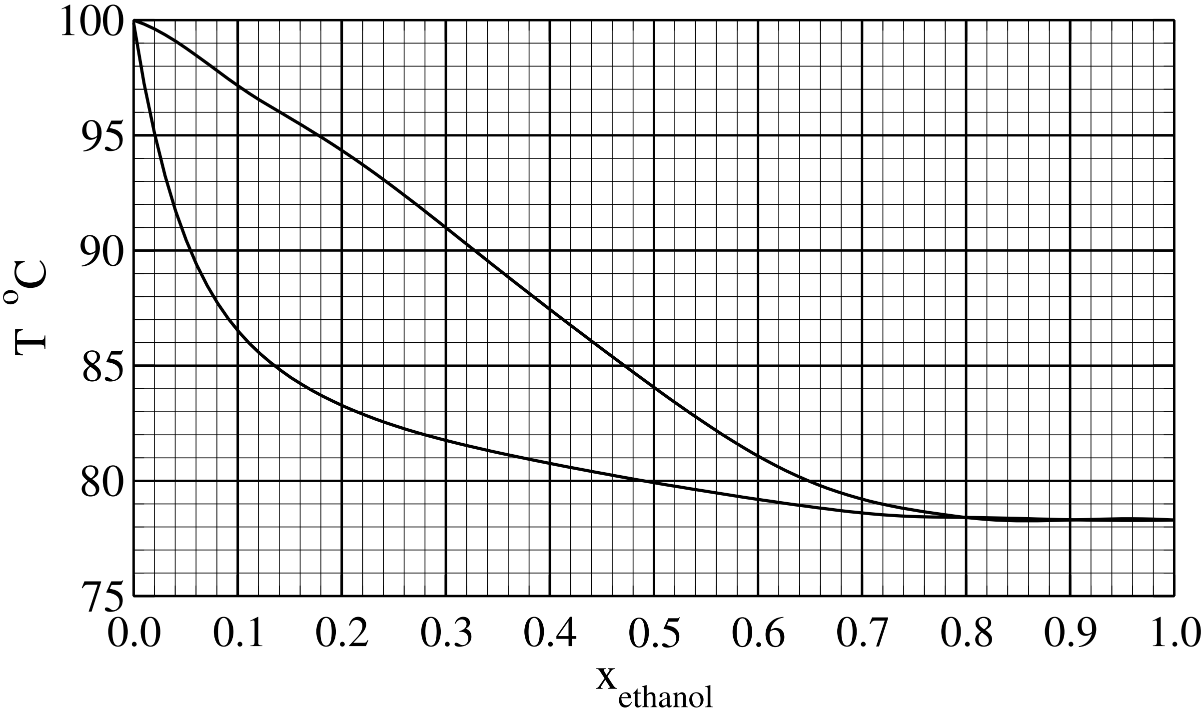

Figure 2: VLE diagram for ethanol-water mixtures at a pressure of 1 atm. This figure is needed for Q. 2a).

If you use this graph, you must attach it to your exam booklet using the provided tag.

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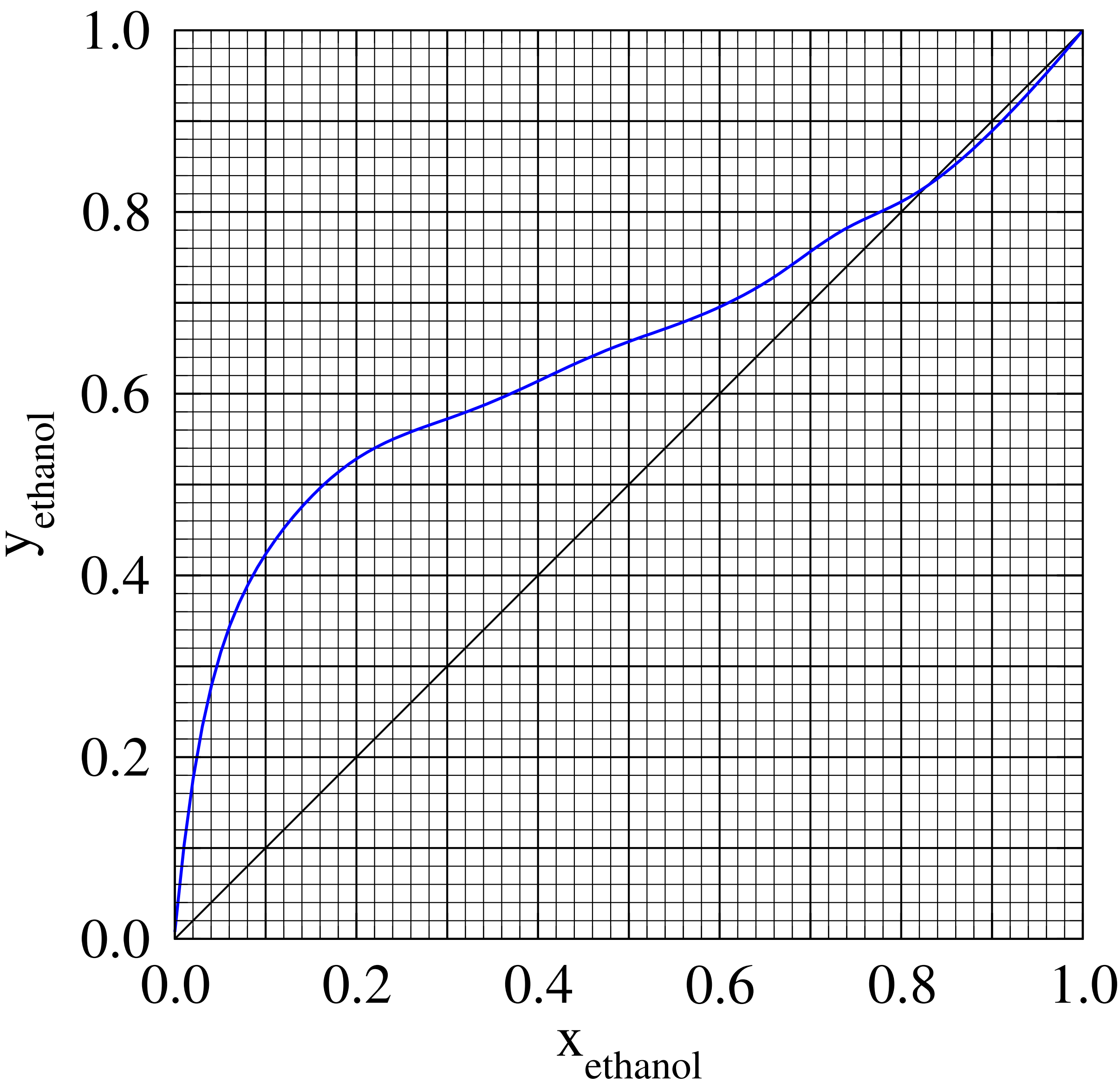

Figure 3: VLE diagram for ethanol-water mixtures at a pressure of 1 atm. This figure is required for Q. 2c) and Q. 3b).

If you use this graph, you must attach it to your exam booklet using the provided tag.

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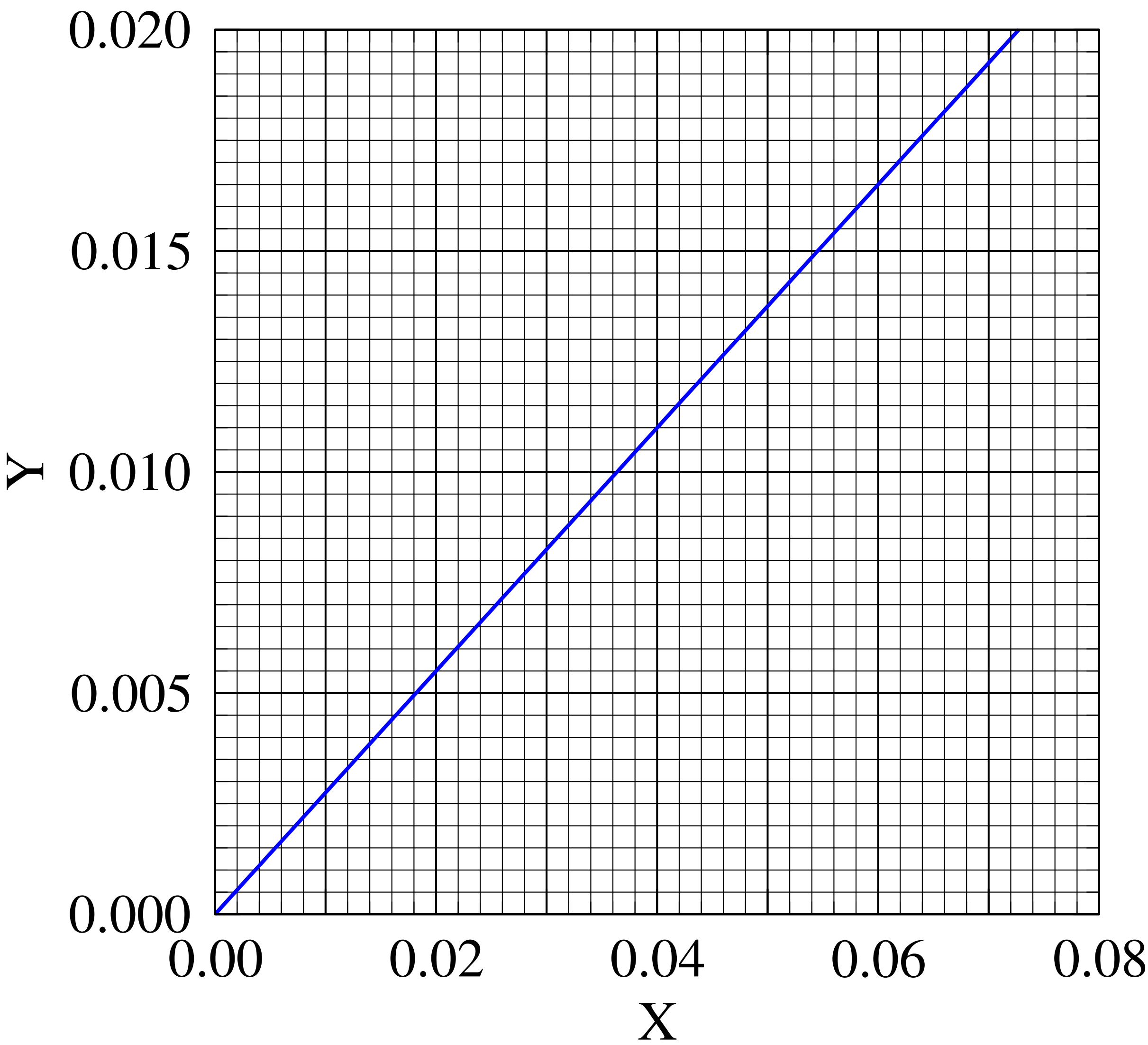

Figure 4: An X-Y graph for the coal gas scrubber in Q. 4.

If you use this graph, you must attach it to your exam booklet using the provided tag.

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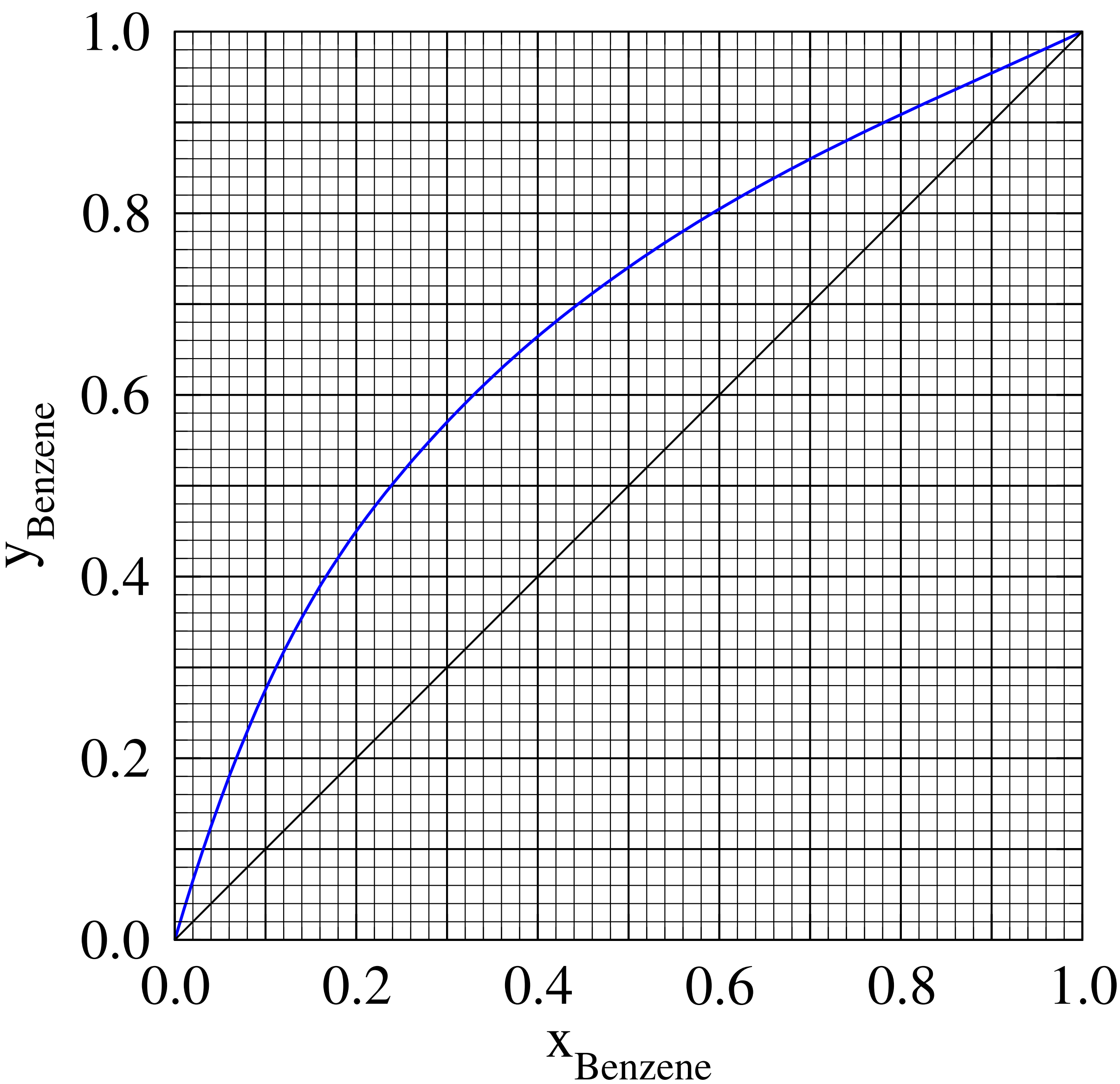

Figure 5: VLE diagram for benzene-toluene mixtures at 1 atm. This figure is required for Q. 6.