UNIVERSITY OF ABERDEEN SESSION 2012–2013

Degree Examination in EG3570 Separation Processes

24th May 2013 9 am – 12 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

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

$$y_m = x_{m+1}\frac{L_m}{V_m} - x_W\frac{W}{V_m}$$

State any assumptions you make and discuss their range of validity. [5 marks]

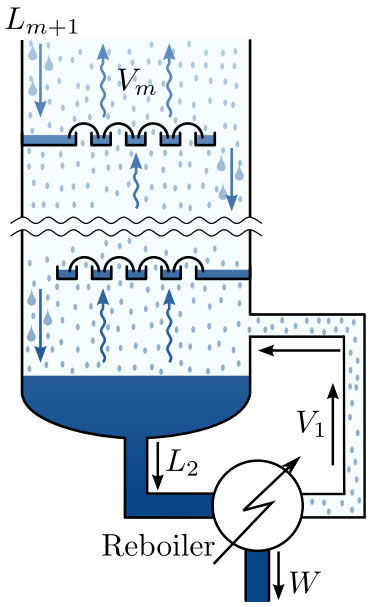

Figure: A diagram of the streams in the stripping section of a distillation column.

b) Explain why the stripping section operating line equation is inconvenient to use when compared to the enrichment operating line if the reflux ratio and the q value are selected as the design variables. [3 marks]

c) Determine the location of one point on the stripping operating line. [2 marks]

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

e) A knockout drum is used to remove condensate from a 8 kmol/s methanol vapour stream. The vapour stream enters the knockout drum at a temperature of 72°C and contains 5 mol% water. Determine the exit concentration of the vapour and liquid streams if 0.5 kmol/s of condensate is collected in the drum.

You may assume methanol has a constant relative volatility of $\alpha = 3.9$ when compared with water. [7 marks]

Question 2

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) A 10,000 kmol benzene-tolulene mixture is sent for batch distillation at atmospheric pressure. Integrated VLE data is available in Fig. 1 and standard VLE data is available in Fig. 2.

i) The distillation is begun and the initial vapour concentration is 60 mol% benzene. Determine the initial liquid concentration in the still. [2 marks]

ii) Distillation is continued until the produced vapour concentration drops to 40 mol% benzene. Determine the amount of liquid remaining in the still. [6 marks]

iii) Calculate the average concentration of the collected distillate. [2 marks]

Question 3

a) Derive the operating line equation for an absorber, given below. Clearly state any assumptions that you make. [8 marks]

$$\frac{y_{A,n+1}}{1 - y_{A,n+1}} = \frac{L'}{V'}\frac{x_{A,n}}{1 - x_{A,n}} + \frac{y_{A,1}}{1 - y_{A,1}} - \frac{L'}{V'}\frac{x_{A,0}}{1 - x_{A,0}}$$

b) Simplify the operating line equation to a linear form using the assumption of low absorbent concentrations. Discuss how these conditions are compatible with the use of Henry's law. [4 marks]

c) A gas mixture of air and SO_2 comes into contact with pure water at 293 K and 4 bar in a single stage equilibrium mixer. The partial pressure of SO_2 in the inlet gas is 0.1 bar and the total inlet gas flow-rate is 5.13 kmol/s. The inlet flow rate of water is 2 kmol/s and the outlets are in equilibrium. Using the Henry's law expression below, calculate the compositions and flow rates of all streams.

$$P_A = \mathcal{H}_A\, x_A$$

where $\mathcal{H}_{SO_2} = 29.98$ bar at 293 K. [8 marks]

PART B: Answer TWO Questions From THREE

Question 4

A hot product stream, containing 40 mol% of a volatile lipid, from a reactor producing soap is to be continuously distilled in a plate tower until it reaches a purity of 90 mol% and a waste stream containing less than 10 mol% of lipid. As the lipid mixture increases in concentration it begins to foam and the column plate efficiencies begin to drop. The theoretical and the effective "Murphree" VLE lines for the column are plotted in Fig. 3.

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

a) The column is operating at a reflux ratio of $R = 1.5 \times R_{min}$. Using the effective VLE line, determine the operating reflux ratio of the column if the feed mixture is supplied to the column as a saturated liquid. [5 marks]

b) Determine the number of stages in the column required to perform the distillation. Assume that the column is fitted with a partial reboiler and a total condenser. [8 marks]

c) Define the Murphree plate efficiency, and calculate its values for the two stages above the feed plate. [7 marks]

Question 5

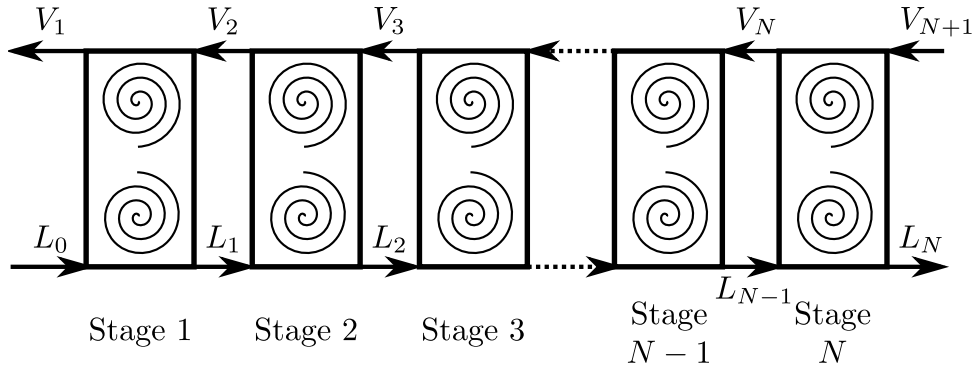

Figure: The stream numbering within a multi-stage absorber

Air is dried by contacting it with a solution of sulphuric acid in a counter-current absorber column. The air enters the absorber with 2.7 mol% of water and leaves with 0.8 mol% of water. Absorbent is supplied to the column at a concentration of 67 mol% H_2SO_4 and 33 mol% water, and exits the column at a concentration of 40 mol% H_2SO_4. The column is operating at atmospheric pressure (760 mmHg) and at a temperature of 25°C. You may assume that water is the only component transferred between the phases (H_2SO_4 remains in the liquid phase and no air dissolves).

a) Determine the ratio of the flow rate of dry air to the flow rate of H_2SO_4. [8 marks]

b) Using the equilibrium data provided in Table 1, determine the number of equilibrium stages required to perform the absorption. Plot your graph in x-y coordinates and ensure that you adequately capture the curvature of the operating line (or use X-Y coordinates).
Note: If you draw on the graph provided (Fig. 4), remember to include it in your exam booklet for marking. [12 marks]

Table 1: Partial pressure data for water over aqueous solutions of sulphuric acid at 25°C.

Liquid Water Conc. (mol%)	Partial Pressure of Water (mmHg)
80	20.8
70	17.8
60	13.5
50	8.45
40	3.97
30	1.03
20	0.124
10	0.00765

Question 6

A continuous distillation column is being used to separate benzene from toluene. There are six plates above the feed plate and the column is operated with a reflux ratio of 3. When the feed composition is 40 mol% benzene, the top product has a composition of 97 mol% benzene. VLE data for the system is provided in Fig. 2.
Note: If you draw on the graph provided (Fig. 2), remember to include it in your exam booklet for marking.

a) What range of q-values will yield the top-product specification? [10 marks]

b) Discuss what the optimum q-value for the column is and how it affects the costs of construction and operation. [5 marks]

c) Using the optimum q-value, calculate how many plates/trays are required below the feed tray. You may assume that a partial reboiler is used and the bottoms product is 8 mol% Benzene. [3 marks]

d) Why would it be impractical to operate the column with a fully vapourised feed ($q = 0$)? [2 marks]

END OF PAPER

DATASHEET

Operating lines:

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

$$y_m = x_{m+1}\frac{L_m}{V_m} - x_W\frac{W}{V_m} \qquad \text{Stripping line} \qquad (2)$$

$$y = x\frac{q}{q-1} - \frac{x_F}{q-1} \qquad q\text{-line} \qquad (3)$$

$$\frac{y_{A,n+1}}{1-y_{A,n+1}} = \frac{L'}{V'}\frac{x_{A,n}}{1-x_{A,n}} + \frac{y_{A,1}}{1-y_{A,1}} - \frac{L'}{V'}\frac{x_{A,0}}{1-x_{A,0}} \qquad \text{Absorption} \qquad (4)$$

Relative volatility

$$y_A = \frac{\alpha\, x_A}{1+(\alpha-1)x_A} \qquad (5)$$

Rayleigh's equation

$$\ln\left(\frac{L_{final}}{L_{initial}}\right) = \int_{x_{initial}}^{x_{final}} \frac{\mathrm{d}x}{y-x} \qquad (6)$$

If the relative volatility is constant:

$$\ln\left(\frac{L_{final}}{L_{initial}}\right) = (\alpha-1)^{-1}\ln\left(\frac{x_{final}(1-x_{initial})}{x_{initial}(1-x_{final})}\right) + \ln\left(\frac{1-x_{initial}}{1-x_{final}}\right) \qquad (7)$$

Quadratic equation:

$$a\,x^2 + b\,x + c = 0 \qquad\qquad x = \frac{-b \pm \sqrt{b^2 - 4\,a\,c}}{2\,a} \qquad (8)$$

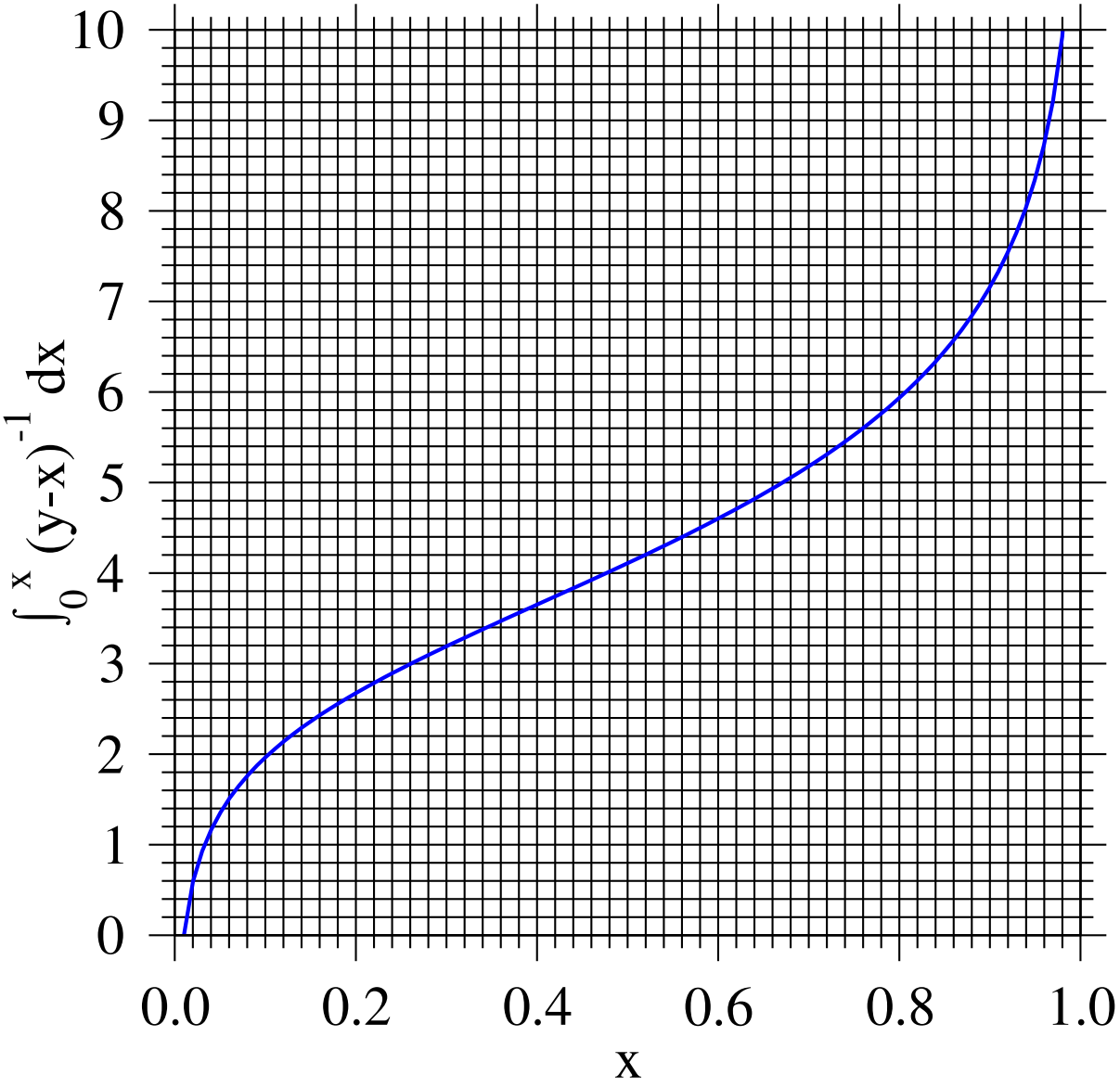

Figure 1: Integrated VLE diagram for benzene-tolulene mixtures at a pressure of 1 atm. This figure is needed for Q. 2.

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

Student ID:

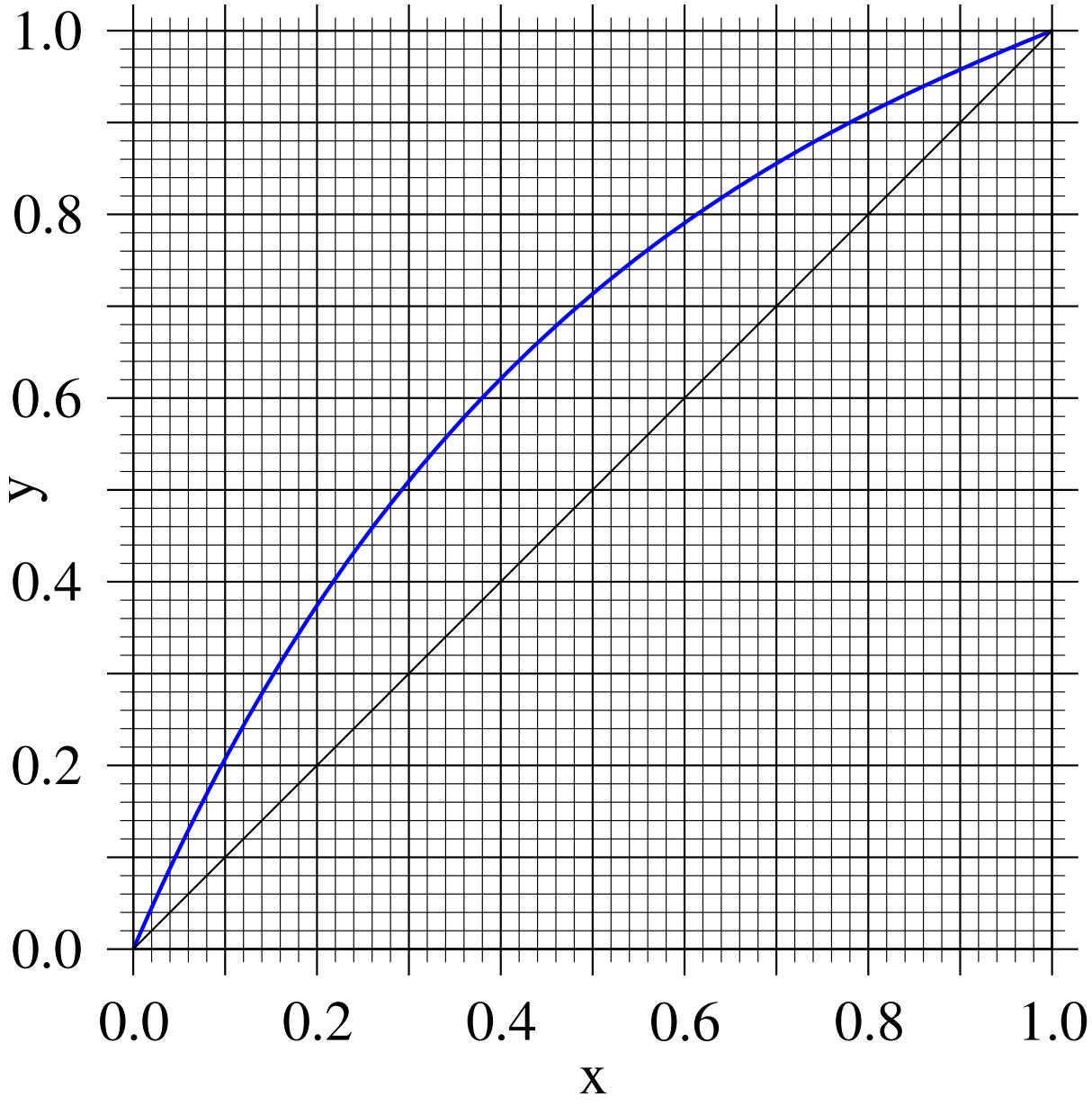

Figure 2: VLE diagram for benzene-tolulene mixtures at a pressure of 1 atm. This figure is needed for Q. 2 and Q. 6.

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

Student ID:

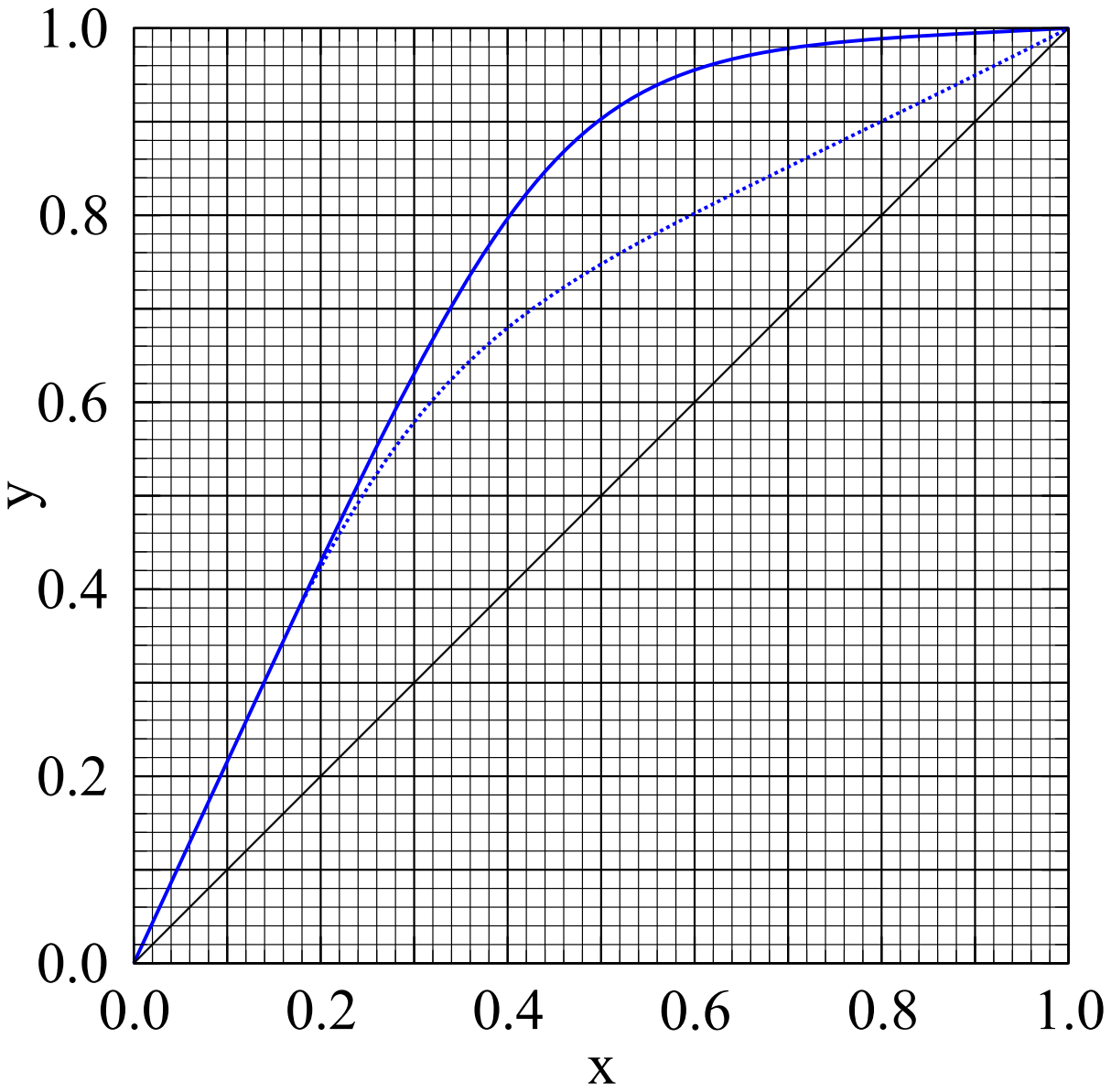

Figure 3: VLE diagram for the lipid mixture. This figure is required for Q. 4).

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

Student ID:

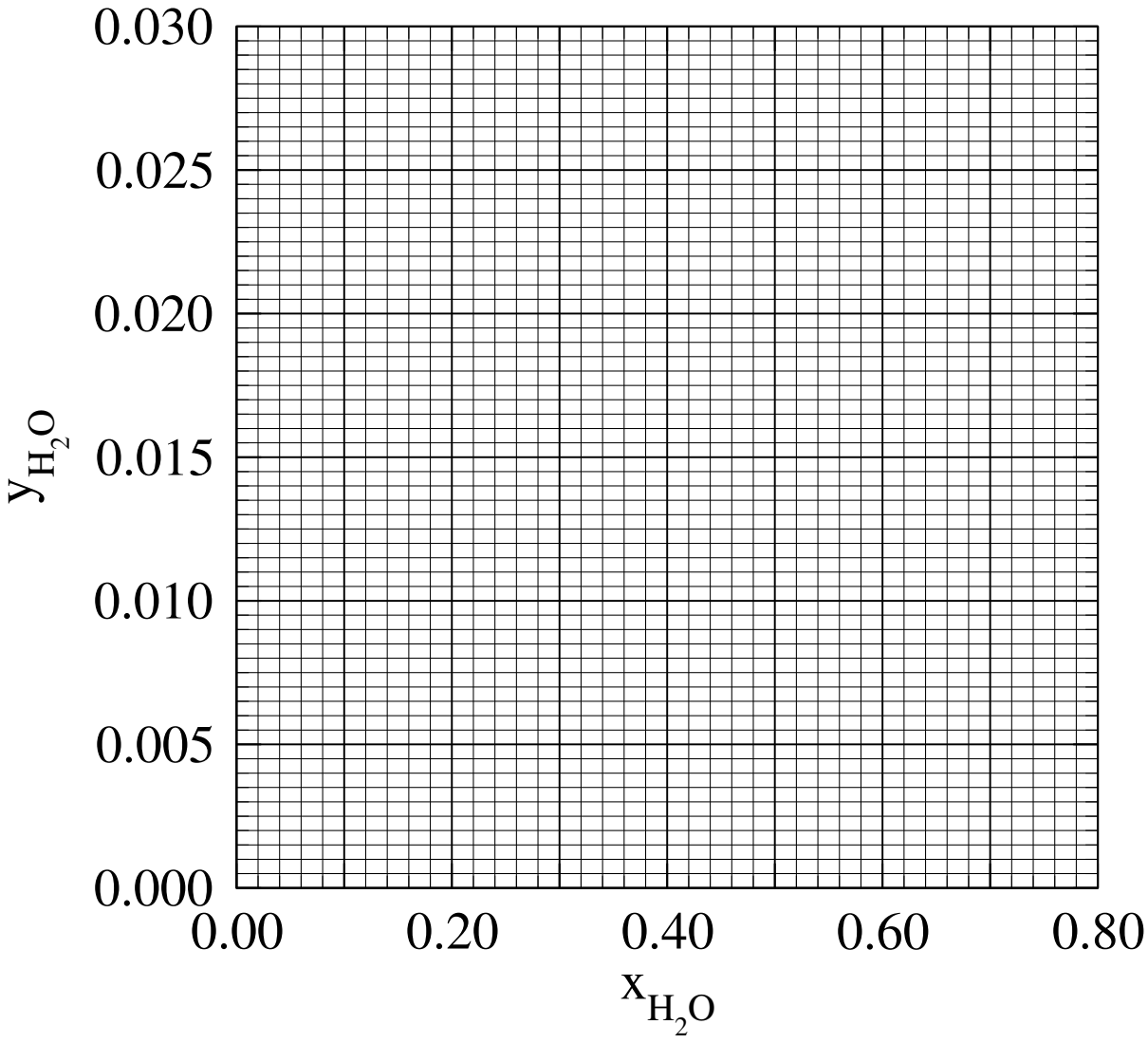

Figure 4: Blank graph for the air dryer in Q. 5.