# Charles Darwin University

Final Examination

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| Family Name | | | | | | |
| Given Name/s | | | | | | |
| Student Number | | | | | | |
| Teaching Period | Semester 1, 2019 | | | | | |

| ENG341 – Separation Process Principles | DURATION | |
|---|---|---|
| | | |
| | Reading Time: | 10 minutes |
| | Writing Time: | 180 minutes |
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**INSTRUCTIONS TO CANDIDATES**

- The paper has only one section. Answer All Questions.
- All calculations to be performed in the answer booklet issued
- Please refer to the Appendix at the end of the question for necessary equations and diagram required.
- Please attach Equilibrium diagrams supplied in the Appendix to your answer booklets where applicable.

**EXAM CONDITIONS**

You may begin writing from the commencement of the examination session. The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

No dictionaries are permitted

| ADDITIONAL AUTHORISED MATERIALS | EXAMINATION MATERIALS TO BE SUPPLIED |
|---|---|
| No additional printed material is permitted | 1 x 20 Page Book<br>1 x 8 Page Book<br>2 x Scrap Paper<br>Graph paper |

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Total Number of Marks: 100

All questions should be answered in the Answer Booklet provided.
Please Note that All Questions are to be answered.

Marks for each question are indicated. Suggested time allocation: 180 mins

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## Question 1

A distillation column is separating ethanol from water with a total condenser and a partial reboiler. The operating pressure of the column is 1 atm. The bottom and the distillate product are to contain 2 mol % and 72 mol % ethanol, respectively. Two feeds are introduced to the column where feed 1 is near to the top and is a saturated liquid. Feed 1 is flowing at a rate of 300 kmol/h and contains 30 mol% ethanol. Feed 2 is flowing at a rate of 200 kmol/h and contains 40 mol% ethanol. The quality of the feed 2 is saturated vapor. The external reflux ratio is 1 and the reflux is saturated liquid. Vapor liquid equilibrium (VLE) plot for ethanol-water mixture at 1 atm is provided in Fig. 1 in Appendix I. Based on the given information and VLE plot, answer the following:

i. Derive the operating line equations for all sections in the column.

(Marks: 06)

ii. Determine the total vapor and liquid flow rates for each section.

(Marks: 12)

iii. Determine the number of theoretical plates required to perform the given separation and indicate the location of optimum feed stage.

(Marks: 07)

## Question 2

$CO_2$ is to be stripped from a liquid stream using air (pure air). The inlet liquid flowing at 1500 kg/hr contains 20 wt. % $CO_2$. The exit liquid is to contain 0.1 wt. % $CO_2$. The separation is performed using a stripper of counter-current configuration with four contacting stages. The equilibrium diagram for $CO_2$ stripping using air is available in Fig. 2 in Appendix II. With the given information and the equilibrium plot, answer the following:

i. Determine the minimum ratio of water to air, (L/G)max and explain the significance of (L/G)max.

(Marks: 08)

ii. What is the concentration of $CO_2$ in the outlet gas stream? You are expected to provide neat solution using Fig. 2.

(Marks: 12)

iii. Determine the inlet air flow rate to the stripper?

(Marks: 05)

## Question 3

You are required to remove acetic acid from water using isopropyle ether as solvent with a liquid-liquid extraction unit. The operation is at 20°C and 1 atm. The feed is 0.45 wt. fraction acetic acid and 0.55 wt fraction water. Feed flow rate is 2000 kg/h. A counter current system is used. Pure solvent is used. We desire an extract stream that is 0.20 wt. fraction acetic acid and a raffinate that is 0.20 wt. fraction acetic acid. Equilibrium plot for water- acetic acid- isopropyle ether is available in **Fig. 3**, **Appendix III**. Using the right-angle plot:

i. Determine the flow rate of solvent.

(Marks: 10)

ii. Estimate the number of stages required for the given separation.

(Marks: 10)

iii. Find the composition of each stream leaving each stage.

(Marks: 05)

## Question 4

A sieve-plate distillation column is designed with 12 inch tray spacing to operate at a pressure of 3 atm. The column has a total condenser and total reboiler. Internal reflux ratio is L/V = 0.8 and distillate flow rate is 1400 lbmol/h. The value of flow parameter is 0.3 and flooding velocity is obtained as 6.56 ft/s. However, the current operating pressure causes a very high distillation temperature; as a consequence high level of thermal degradation occurs. Therefore it is essential to reduce the column's operating pressure. Assume that vapor in the column act as an ideal gas. Also assume that liquid density is very large compared to the gas density and gas density is unaffected by temperature. The correlation between flow parameter and capacity factor for sieve tray column is provided in **Fig. 4 in Appendix IV.**

i. If you are advised to reduce the operating pressure to 0.75 atm, estimate the new flooding velocity for the column.

(Marks: 15)

ii. Now assume operating vapor velocity is 75% of the new flooding velocity and fraction of the column cross-sectional area that is available for vapor flow rate is 0.90. Estimate required diameter at the top of the column when column is operated at 342K and 0.75 atm. Diameter of the column can be expressed as

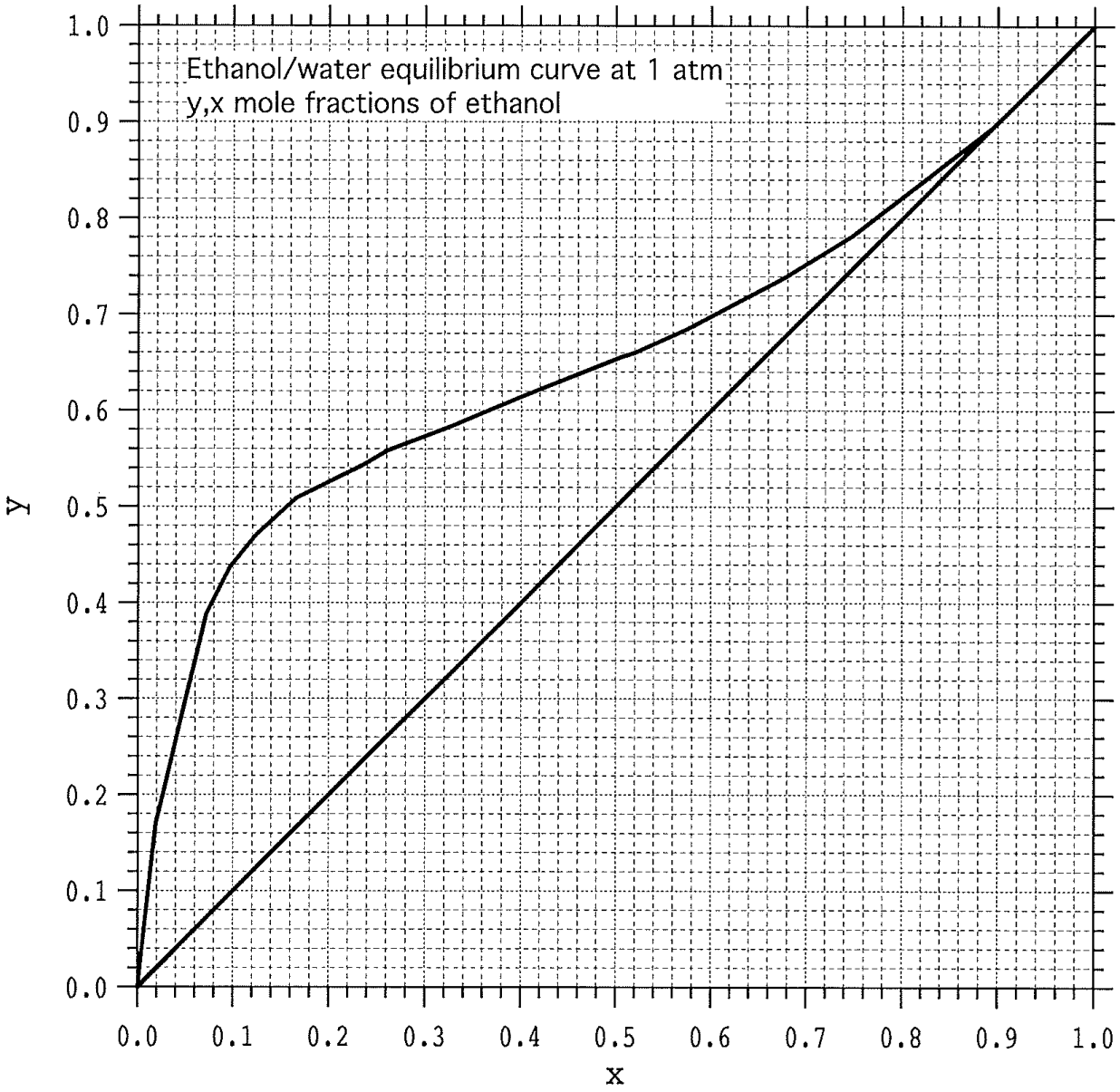
$$\text{Dia} = \sqrt{\frac{4VR\Gamma}{\pi\,\eta\,(3600)p(\text{fraction})u_{\text{flood}}}}, \qquad \text{ft}$$

Where, $\eta$ = fraction of column cross sectional area available for vapor flow rate; $V$= vapor or gas flow rate; $u_{flood}$ = flooding velocity; Universal gas constant, R = 1.314 atm,ft$^3$/(K. lbmol), $p$ = operating pressure.

(Marks: 10)

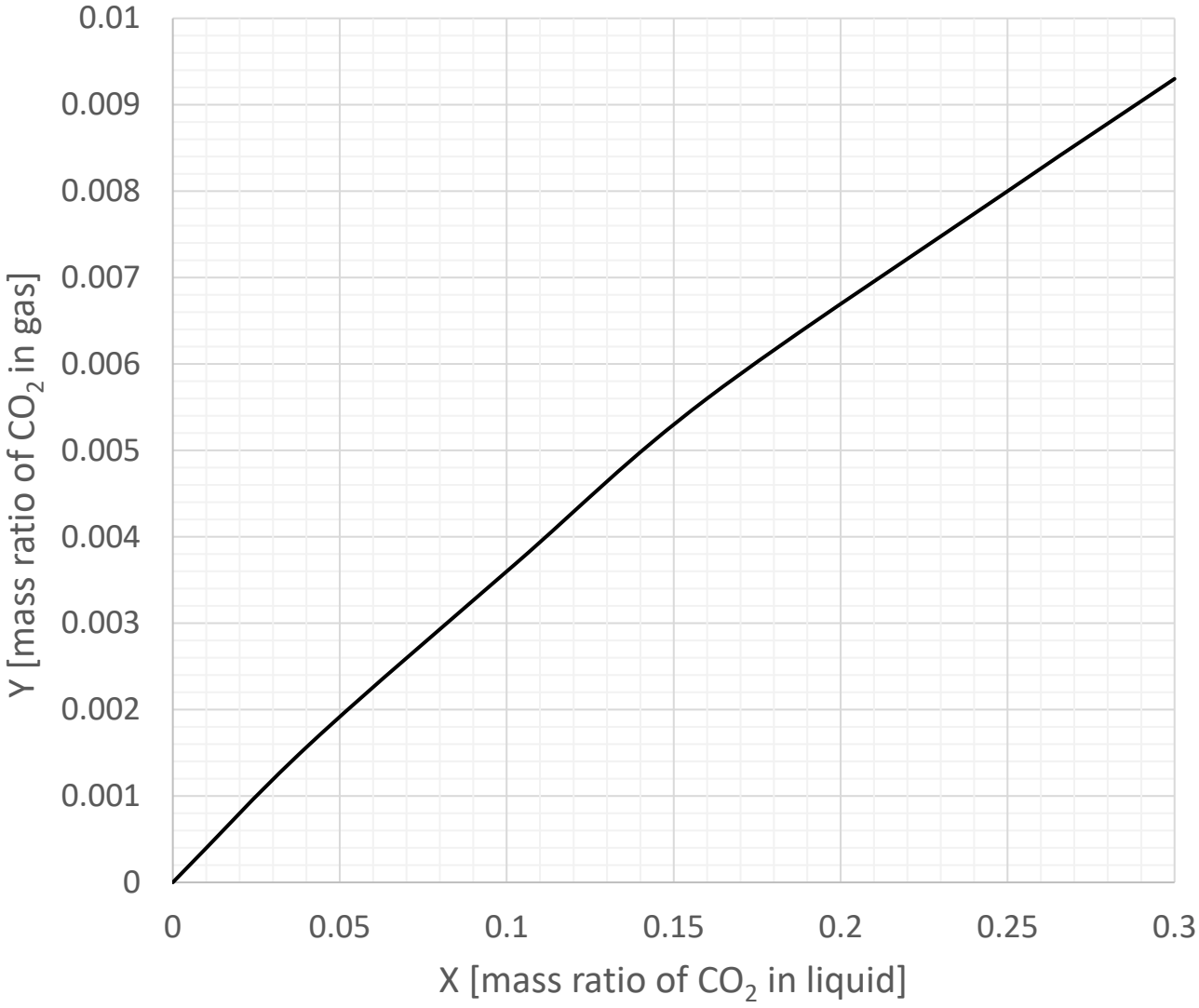
APPENDIX I

**Figure 1:** x-y diagram for ethanol-water system corresponding to **Question 1.**



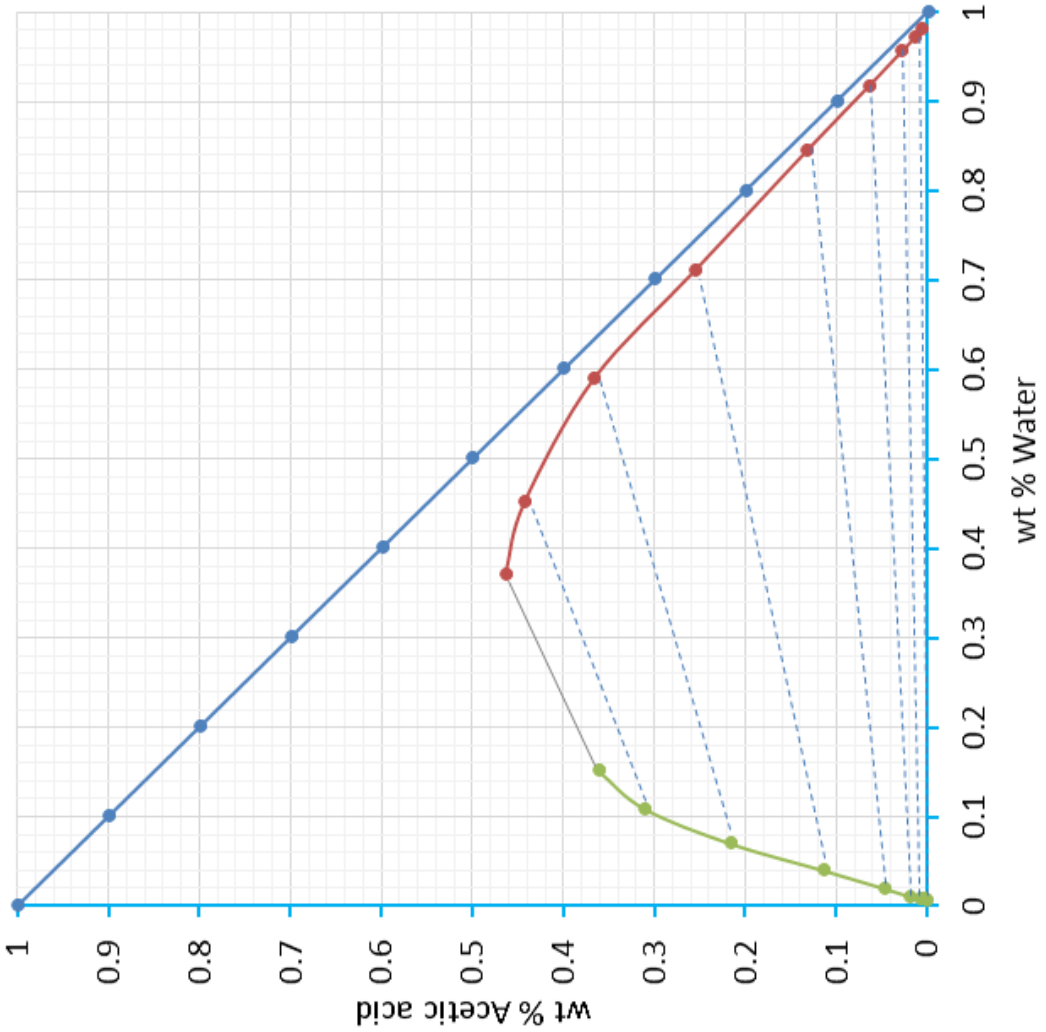
APPENDIX II

**Figure 2:** Equilibrium curve for $CO_2$ stripping using air corresponding to **Question 2. Take note of the axis.**



APPENDIX III

**Figure 3:** Equilibrium plot for water-acetic acid-isopropyl ether at 20°C and 1 atm corresponding to Question 3.



APPENDIX IV

Figure 4: Capacity factor for flooding of sieve trays corresponding to Question 4.

*Where, $C_{sb,f}$ = capacity factor, $F_{lv}$ = flow parameter, $U_{n,f}$ = flooding velocity , $\sigma$=surface tension, $L$= liquid flow rate and $G$= gas flow rate, $\rho_l$ = density of liquid, $\rho_g$ = density of gas=($n.MW)/G$, $n$= no of moles of the gas, $MW$= molecular weight of the gas.*