UNIVERSITY OF KWAZULU-NATAL

INYUVESI YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: JUNE 2019

COURSE AND CODE: ADVANCED MASS TRANSFER ENCH4MT

DURATION: 2 HOURS

TOTAL MARKS: 60

INTERNAL EXAMINER: DR W. M. NELSON

INTERNAL MODERATOR: PROF. P. NAIDOO

EXTERNAL MODERATOR: PROF. C. SCHWARZ

INSTRUCTIONS:

1. **ALL** questions should be attempted. **Answer in ink.**
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. A formulae sheet is provided on Pages 4 & 5
5. All flows and compositions are on a **molar basis.**

QUESTION 1

A stream consisting of benzene, methylcyclohexane, toluene, and ethylbenzene is to be purified into four products using a conventional distillation sequence. The order of the sequence is to be determined. The feed to the separation process is a saturated liquid. Information for the feed is available in table 1. The process will operate at atmospheric pressure.

Table 1: Pure component and feed information

Component	Boiling point[a] / °C	Vapour pressure[b] / bar	Purity / %	Flowrate / kmol.hr^{-1}
Benzene	80.1	1.82	97	40
Methylcyclohexane	100.7	1.01	99.9	25
Toluene	110.67	0.75	99	10
Ethylbenzene	136.16	0.35	99	30

[a] Normal boiling point
[b] Vapour pressure at the feed temperature.

1.1. Determine a separation sequence to purify all products. Sketch the sequence and explain how this sequence was determined.

[5]

1.2. Approximate the minimum number of theoretical trays for the first column in the sequence, given that the recovery of the light key is 99.99%. Additionally, determine the distribution of the non-key components at total reflux.

[12]

1.3. Provide a **solution strategy** to estimate the minimum reflux ratio for this distillation column (only the method is required, not the actual value for the minimum reflux).

[4]

1.4 Provide a sketch approximating the change in annual cost (operating, capital, and total; y-axis) with the reflux ratio (x-axis), indicating the location of the minimum and optimal reflux ratio.

[3]

1.5. Multi-effect distillation is an example of a heat-integrated distillation configuration that can potentially reduce energy requirements. Provide a sketch and brief discussion of the 'feed splitting' configuration.

[5]

TOTAL /29/

QUESTION 2

The binary mixture of acetone + heptane exhibits positive deviation from Raoult's law. This mixture exhibits a minimum boiling azeotrope at atmospheric pressure. A solvent can be used to enable the production of two pure products. Consider the implementation of **either toluene or benzene** as a solvent in the separation process, to purify an equimolar mixture of acetone and heptane. Information regarding pure component and mixture boiling points are located in table 2.

Table 2: Mixture and pure component boiling points at 1 atm.

T / °C	$x_{acetone}$	$x_{benzene}$	$x_{heptane}$	$x_{toluene}$
55.8*	**0.927**	0.000	**0.073**	0.000
56.1	**1.000**	0.000	0.000	0.000
80.1	0.000	**1.000**	0.000	0.000
98.4	0.000	0.000	**1.000**	0.000
110.7	0.000	0.000	0.000	**1.000**

* Minimum-boiling azeotrope.

Table 3: Activity coefficients at infinite dilution for acetone and heptane in the solvent (benzene or toluene).

	Benzene	Toluene
Acetone	1.2	1.7
Heptane	1.7	1.3

2.1. Consider a separation process to purify acetone and heptane using **toluene** as an entrainer. Define the process. Sketch the column sequence to purify acetone and heptane. On the sketch ensure that all potential products, columns, and streams are labeled and clearly defined. In addition, please draw all necessary material balance lines and include labels on the residue curve map (figure 1).

[10]

2.2. Consider a separation process to purify acetone and heptane using **benzene** as an entrainer. Define the process. Sketch the column sequence to purify acetone and heptane. On the sketch ensure that all potential products, columns, and streams are labeled and clearly defined. In addition, please draw all necessary material balance lines and include labels on the residue curve map (figure 2).

[10]

TOTAL /20/

QUESTION 3

Desalination of ocean water via reverse osmosis is a convenient method for the provision of potable water, particularly, if the desalination plant is able to be run on renewable or nuclear energy.

3.1. Discuss the energy usage and recovery with regard to the reverse osmosis process.

[3]

3.2. List the post-treatment steps of the desalinated water in reverse osmosis.

[2]

3.3. Define the membrane type and membrane arrangement that may be used in the reverse osmosis process.

[3]

3.4. Discuss how the brine from such a process should be ideally discarded.

[3]

TOTAL /11/

FORMULAE SHEET

Summation equation

$$\sum_{i=1}^{c} x_i = 1; \quad \sum_{i=1}^{c} y_i = 1;$$

Isothermal Flash calculation

$$f(\Psi) = \sum_{i=1}^{c} \frac{z_i(1-K_i)}{1+\Psi(K_i-1)} = 0$$

Bubble point equation

$$\sum_{i=1}^{c} z_i K_i = 1$$

Dew point equation

$$\sum_{i=1}^{c} z_i / K_i = 1$$

Fenske Equation

$$N_{\min} = \frac{\log\{[(x_{i,N+1})/x_{i,1}][(x_{j,1})/x_{j,N+1}]\}}{\log \alpha_m}$$

$$N_{\min} = \frac{\log[(d_i/d_j)(b_j/b_i)]}{\log \alpha_m}$$

Distribution of non-key components

$$f_i = d_i + b_i$$

$$b_i = \frac{f_i}{1+(d_r/b_r)(\alpha_{i,r})_m^{N_{\min}}}$$

$$d_i = \frac{f_i(d_r/b_r)(\alpha_{i,r})_m^{N_{\min}}}{1+(d_r/b_r)(\alpha_{i,r})_m^{N_{\min}}}$$

Underwood Equations (Class 1)

$$\frac{(L_\infty)_{min}}{F} = \frac{\left(\frac{L_F}{F}\right)\left[\frac{Dx_{LK,D}}{L_F x_{LK,F}} - (\alpha_{LK.HK})_F \frac{Dx_{HK,D}}{L_F x_{HK,F}}\right]}{(\alpha_{LK.HK})_F - 1}$$

Underwood Equations (Class 2)

$$1-q=\sum_{i=1}^{c}\frac{\alpha_{i,r}z_i}{\alpha_{i,r}-\phi}$$

$$\sum_{i=1}^{c}\frac{\alpha_{i,r}x_{i,D}}{\alpha_{i,r}-\phi}=1+R_{\min}$$

Gilliland Correlation (Molokanov Equation)

$$Y=\frac{N-N_{\min}}{N+1}=1-\exp\left[\left(\frac{1+54.4X}{11+117.2X}\right)\left(\frac{X-1}{X^{0.5}}\right)\right]$$

$$X=\frac{R-R_{\min}}{R+1}$$

Kirkbride Equation

$$\frac{N_R}{N_S}=\left[\frac{z_{HK}}{z_{LK}}\left(\frac{x_{LK,B}}{x_{HK,D}}\right)^2\frac{B}{D}\right]^{0.206}$$

Column Sequencing

$$N=\frac{[2(P-1)]!}{P!\,(P-1)!}$$

STUDENT NUMBER: ______________________

DETACH THIS PAGE AND SUBMIT WITH YOUR ANSWER BOOK.

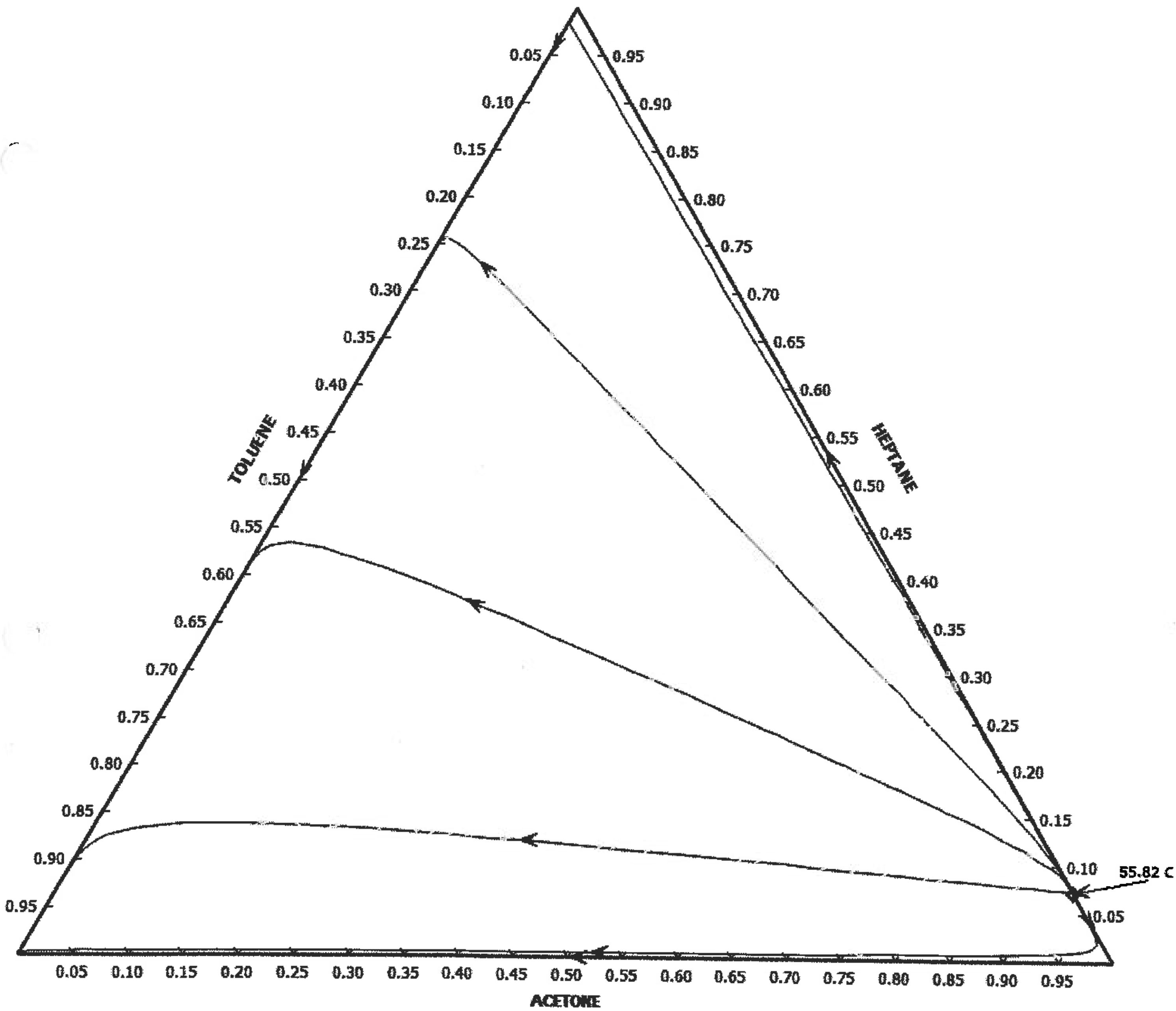

Figure 1. Residue-curve map for acetone, heptane and toluene at 1 atm.

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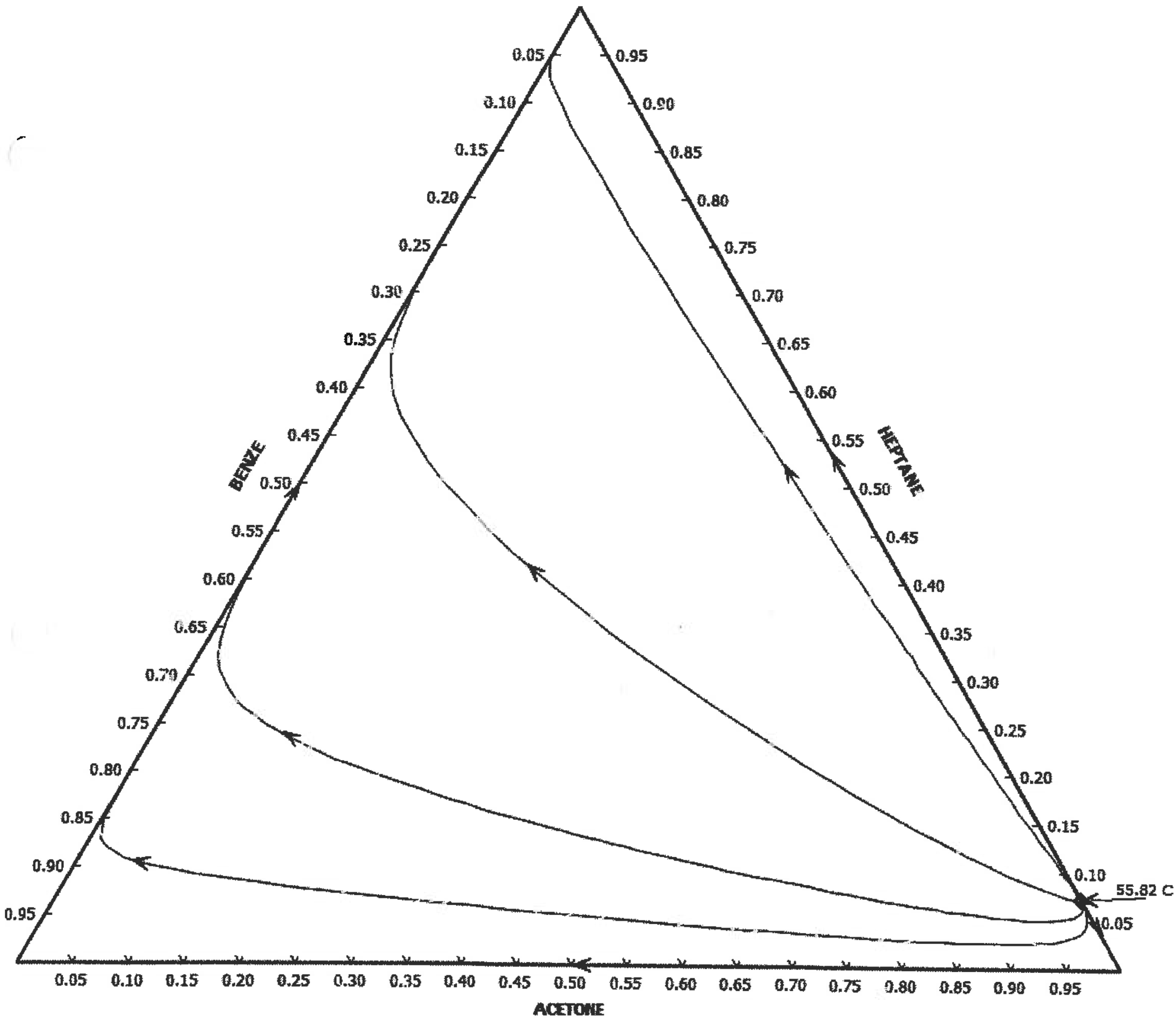

Figure 2. Residue-curve map for acetone, heptane and benzene at 1 atm.