UNIVERSITY OF KWAZULU-NATAL

INYUVESI YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: NOVEMBER 2019

COURSE AND CODE: MASS TRANSFER ENCH3MT

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER(S): MR MG NTUNKA
PROF AH MOHAMMADI

INTERNAL MODERATOR(S): DR WM NELSON

EXTERNAL MODERATOR: DR Y ISA

INSTRUCTIONS:

1. **ALL** questions should be attempted.

2. **Two Answer Books are provided. Label them Books 1 and 2 respectively. Answer Section A in Book 1 and Section B in Book 2.**

3 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.

4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.

5. **DETACH PAGES 7 & 8 AND SUBMIT WITH ANSWER BOOK 1. DETACH PAGE 9 AND SUBMIT WITH ANSWER BOOK 2.**

6. This examination question paper, together with all associated diagrams, **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

SECTION A [ANSWER IN BOOK 1]

QUESTION 1

A straw oil used to absorb benzene (B) from coke-oven gas is to be steam-stripped in a sieve-plate column at atmospheric pressure to recover the dissolved benzene. Equilibrium conditions at the operating temperature are approximated using Henry's law such that $y_B = 0.5x_B$. The oil may be considered non-volatile. The oil enters containing 8 mol% benzene, 75% of which is to be recovered. The steam leaving contains 3 mol% C_6H_6.

a) How many moles of steam are required per 100 mol of oil-benzene mixture?

(2)

b) Calculate the molar ratios of benzene per mol benzene free oil and benzene per mol benzene free steam in the stripper.

(4)

c) Convert the p-x data into molar ratio Y-X data. Plot the equilibrium curve on the graph paper provided.

(5)

d) Determine graphically, the number of theoretical stages required to achieve this separation.

(6)

e) If 85% of the benzene is to be recovered with the same oil and steam rates, how many theoretical stages are required?

(8)

TOTAL /25/

NOTE: Use graph paper provided on page 7 to answer questions c, d and e.

QUESTION 2

A mixture of diethylamine (A) with molecular weight of 73.09 kg/kmol and trimethylamine (B) with molecular weight of 101.1 kg/kmol containing 40 mol% of B is to be separated in a packed distillation column (diameter = 0.75 m) flowing at the rate of 2000 kg/h and a total pressure of 113.3 kPa. The top product should have 97 mol% of diethylamine and the bottom product, 96 mol% trimethylamine. The feed is at its bubble point and the reflux ratio used is twice the minimum. The individual volumetric mass transfer coefficients are:

Table 1: Mass transfer coefficients

Rectifying section:	$k'_x\bar{a} = 600$	and	$k'_y\bar{a} = 170$ kmol/h.m^3
Stripping section:	$k'_x\bar{a} = 750$	and	$k'_y\bar{a} = 200$ kmol/h.m^3

The equilibrium data for the system at the given pressure are given in the table below.

Table 2: x-y data for the system

x	0	0.02	0.104	0.227	0.342	0.424	0.522	0.79	0.923	0.969	1.0
y	0	0.052	0.231	0.451	0.60	0.674	0.755	0.91	0.978	0.988	1.0

a) Solve the distillation column external balance to find the stream feed, distillate and bottom flow rates in kmol/h.

(5)

b) Determine the minimum reflux ratio required to carry out the separation

(3)

c) Perform the internal column balance and plot the operating lines for the rectifying and the stripping sections on the x-y diagram.

(7)

d) By graphical integration, it was estimated that the number of transfer units N_{OG} for the rectifying and stripping section was 5.02 units and 8.7 units respectively. Calculate the the packed height.

(6)

e) Determine the number of theoretical plates and calculate the HETP (in m) of this packing.

(4)

DETACH PAGE 8 AND SUBMIT WITH ANSWER BOOK 1.

TOTAL /25/

SECTION B [ANSWER IN BOOK 2]

QUESTION 3

a) Describe three main solid - liquid extraction processes.

(6)

b) Explain two main difficulties in solid-liquid extraction.

(4)

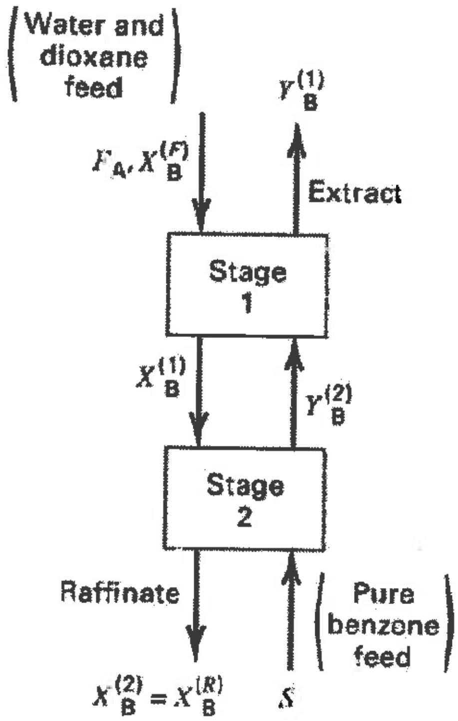
TOTAL /10/

QUESTION 4

For the following counter-current cascade for liquid-liquid extraction, obtain expressions for calculating the ratio of $X_B^{(R)} / X_B^{(F)}$ as a function of Extraction Factor E for two and N separation stages.

Nomenclature

F_A = Feed rate of carrier A
S = Flow rate of solvent C
X_B= Ratio of mass (or moles) of solute B to mass (or moles) of the other components in the feed (F) or raffinate (R)
Y_B= Ratio of mass (or moles) of solute B to mass (or moles) of the other components in the extract (E)
E = Extraction factor
N = Number of separation stages



TOTAL /20/

QUESTION 5

A mixture of Benzene and Toluene containing 50 mole % of Benzene is subjected to a differential distillation at atmospheric pressure till the composition of benzene in the residue is 33 mole %. Average relative volatility may be assumed as 2.16. Calculate the total moles of the mixture distilled:

a) Considering a system of constant relative volatility, the following equation is used for differential distillation:

$$\ln\frac{F}{W} = \frac{1}{\alpha - 1}\ln\frac{x_F(1 - x_W)}{x_W(1 - x_F)} + \ln\frac{1 - x_W}{1 - x_F}$$

Equation 1

In the above equation, F is feed; W is residue; x_F is composition of feed; x_W is composition of residue; and α is relative volatility.

(10)

b) Using the general form of Rayleigh equation and by graphical method. For differential distillation, the following Rayleigh equation is applicable:

$$\ln\frac{F}{W} = \int_{x_W}^{x_F}\frac{dx}{y^* - x}$$

Equation 2

(10)

NOTE: Use graph paper provided on page 9 to answer question b.

TOTAL /20/

SUPPLEMENTARY MATERIAL AND DATA SHEET

McCabe-Thiele Analysis of Binary Distillation:

Equilibrium line: $y = \dfrac{\alpha x}{1+(\alpha-1)x}$ $\quad x = \dfrac{y}{\alpha-(\alpha-1)y}$

Reflux Ratio: $R = \dfrac{L}{D}$; Boil-up Ratio: $V_B = \dfrac{\overline{V}}{B}$

Operating Lines: top: $y = \left(\dfrac{R}{R+1}\right)x + \dfrac{x_D}{R+1}$ $\quad$ bottom: $y = \left(\dfrac{V_B+1}{V_B}\right)x - \dfrac{x_B}{V_B}$

$$y = \frac{L}{V}x + \frac{D}{V}x_D \qquad y = \frac{\overline{L}}{\overline{V}}x - \frac{B}{\overline{V}}x_B$$

q-line:

$q = \dfrac{H_{F,sat.vap.} - H_{F,feed\,T}}{H_{F,sat.vap.} - H_{F,sat.liq}}$; for partially vapourised feed (0<q<1): $q = \dfrac{L_F}{F}$

$$y = \left(\frac{q}{q-1}\right)x - \left(\frac{x_F}{q-1}\right) \qquad \overline{L} - L = qF \qquad \overline{V} - V = (q-1)F$$

Subcooled feed: $q = \dfrac{\Delta H^{vap} + Cp_L(T_b - T_F)}{\Delta H^{vap}}$ $\quad$ Superheated feed: $q = \dfrac{Cp_V(T_d - T_F)}{\Delta H^{vap}}$

Mass Transfer Equations for Packed Distillation Columns:

$\lambda = mV/L$
where $m = dy/dx$ = slope of equilibrium curve

$H_{OG} = H_G + \lambda H_L$

$$HETP = H_{OG}\frac{\ln\lambda}{\lambda-1}$$

Height of packing for non-dilute systems following non-linear equilibrium:

$$l_T = \frac{V'}{S}\int_{yout}^{yin}\frac{dy}{K_y' a(y-y^*)(1-y)^2} = H_{OG}N_{OG}$$

Dilute systems with linear equilibrium

$$l_T = \frac{V}{K_y a S} \int_{yout}^{yin} \frac{dy}{(y - y^*)} \qquad N_{OG} = \frac{\ln\left[\left(\frac{A-1}{A}\right)\left(\frac{y_{in} - Kx_{in}}{y_{out} - Kx_{in}}\right) + \frac{1}{A}\right]}{(A-1)/A}$$

Packed Absorbers:

Diameter of packed columns:

$$D_T = \left[\frac{4VM_V}{fU_f \pi \rho_V}\right]^{0.5} \text{ where V is in [kmol/s]}$$

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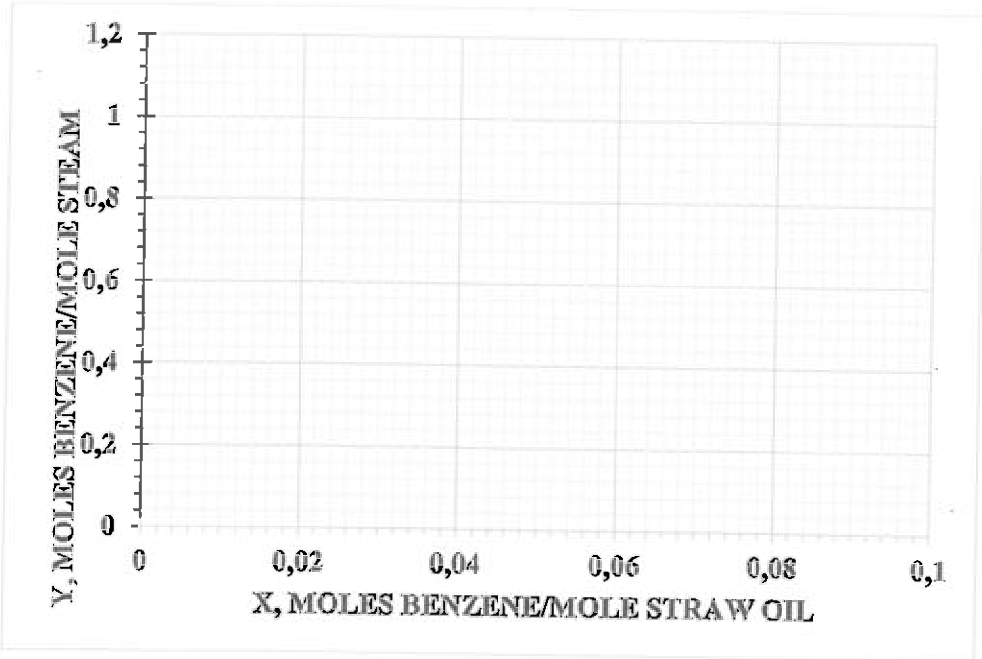
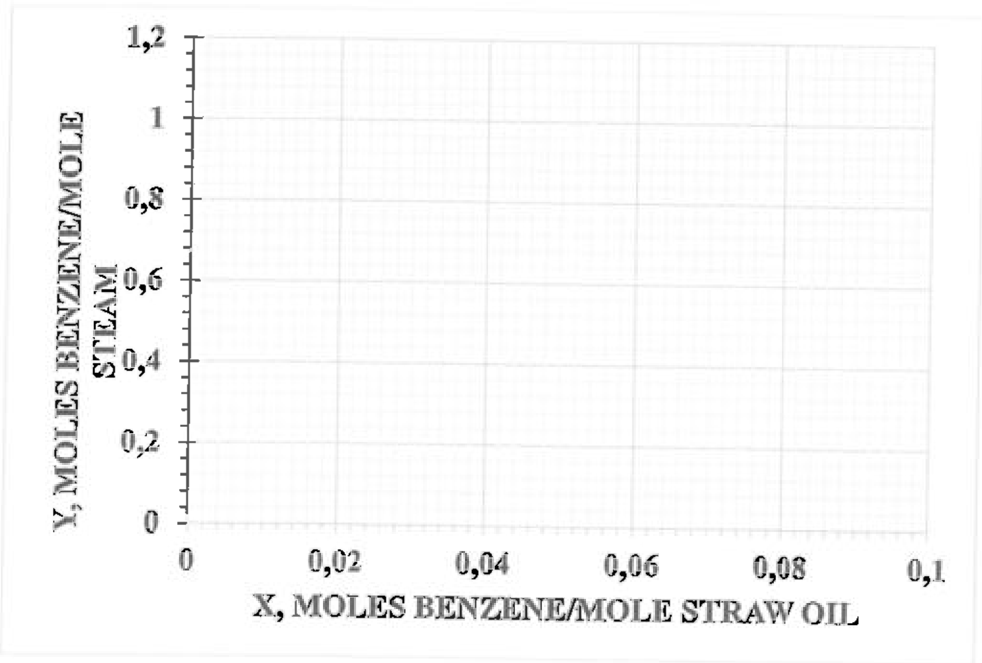
STUDENT NUMBER:

QUESTION 1. c and d



QUESTION 1. c and e



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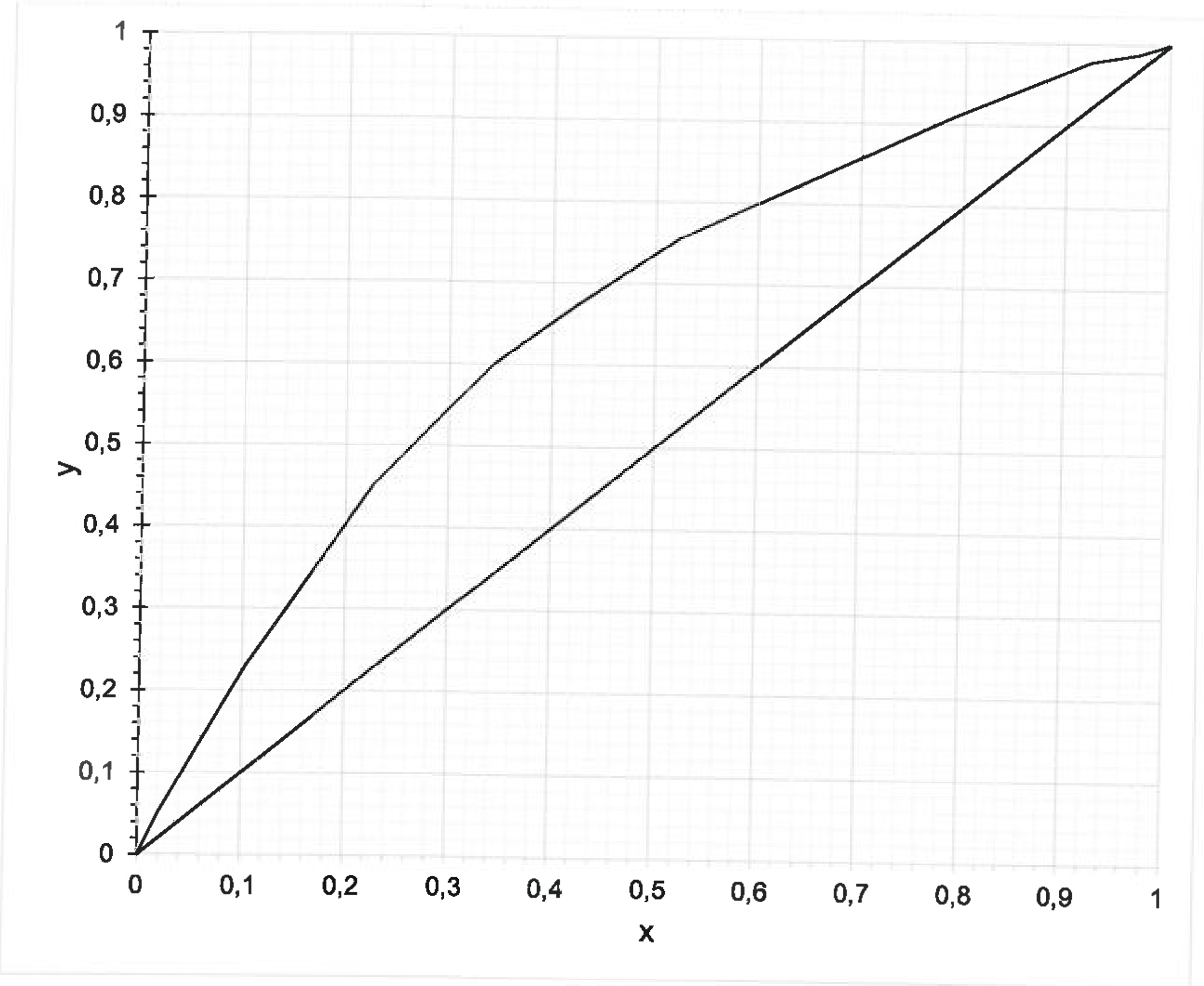
STUDENT NUMBER:

QUESTION 2. c



GRAPH PAPER FOR QUESTION 5 DETACH THIS PAGE AND SUBMIT WITH ANSWER BOOK 2

STUDENT NUMBER: