UNIVERSITY OF
KWAZULU-NATAL

INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

EXAMINATIONS: NOVEMBER 2018

COURSE AND CODE: MASS TRANSFER ENCH3MT

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINERS: DR K OSMAN
PROF AH MOHAMMADI

INTERNAL MODERATOR: DR WM NELSON

EXTERNAL MODERATOR: DR Y ISA

INSTRUCTIONS:

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

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

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. **ENSURE THAT PAGES 4 AND 6 ARE DETACHED AND HANDED IN WITH ANSWER BOOK A.**

6. **ENSURE THAT PAGE 9 IS DETACHED AND HANDED IN WITH ANSWER BOOK B.**

7. **Supplementary material and formulae are provided on page 10.**

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

SECTION A [ANSWER IN BOOK A]

QUESTION 1

A feed containing 100 kg/hr of Ethylene Glycol and 95 kg/hr of Iodobenzene (mvc) is fed continuously to a packed distillation column, giving a distillate stream of 90 mol% Iodobenzene and a bottoms stream of 10 mol% of Iodobenzene. The feed and the reflux enter the column as liquids at the bubble point. The column has a total condenser and an external partial reboiler, and operates at atmospheric pressure with an external reflux ratio of 2.5.

The equilibrium data for iodobenzene/ethylene glycol and a flooding chart for packed columns are given in the graphs on **pages 2 to 4. Page 4 must be DETACHED AND SUBMITTED WITH ANSWER BOOK A.**

a) What effect will the reflux have if it enters the column as a sub-cooled liquid? Briefly describe in words how this would affect your calculations.

(3)

b) Calculate the molar flow rates of the distillate and bottoms streams in [kmol/hr]

(5)

c) Determine graphically, the minimum reflux ratio to achieve this separation

(3)

d) Estimate the column diameter in [m] at 75% of flooding capacity using Figure 1 and 2. Use conditions at the top of the column since the higher vapour flows will occur at the top of the column.

(14)

TOTAL /25

TABLE 1 – INFORMATION FOR QUESTION 1

Mol Wt of Iodobenzene	204 kg/kmol
Mol. Wt. of Ethylene Glycol	62 kg/kmol
Density of Iodobenzene/Ethylene Glycol mixtures (liquid), ρ_L	1230 kg/m^3
Density of Iodobenzene/Ethylene Glycol mixtures (vapour), ρ_V	0.83 kg/m^3
Viscosity of Iodobenzene/ Ethylene Glycol mixtures (liquid), μ_L	3cP
Packing: Berl Saddles	13 mm
Packing factor, F_P	240
Density of Water	1000 kg/m^3
Acceleration due to gravity (g)	9.81 m/s^2

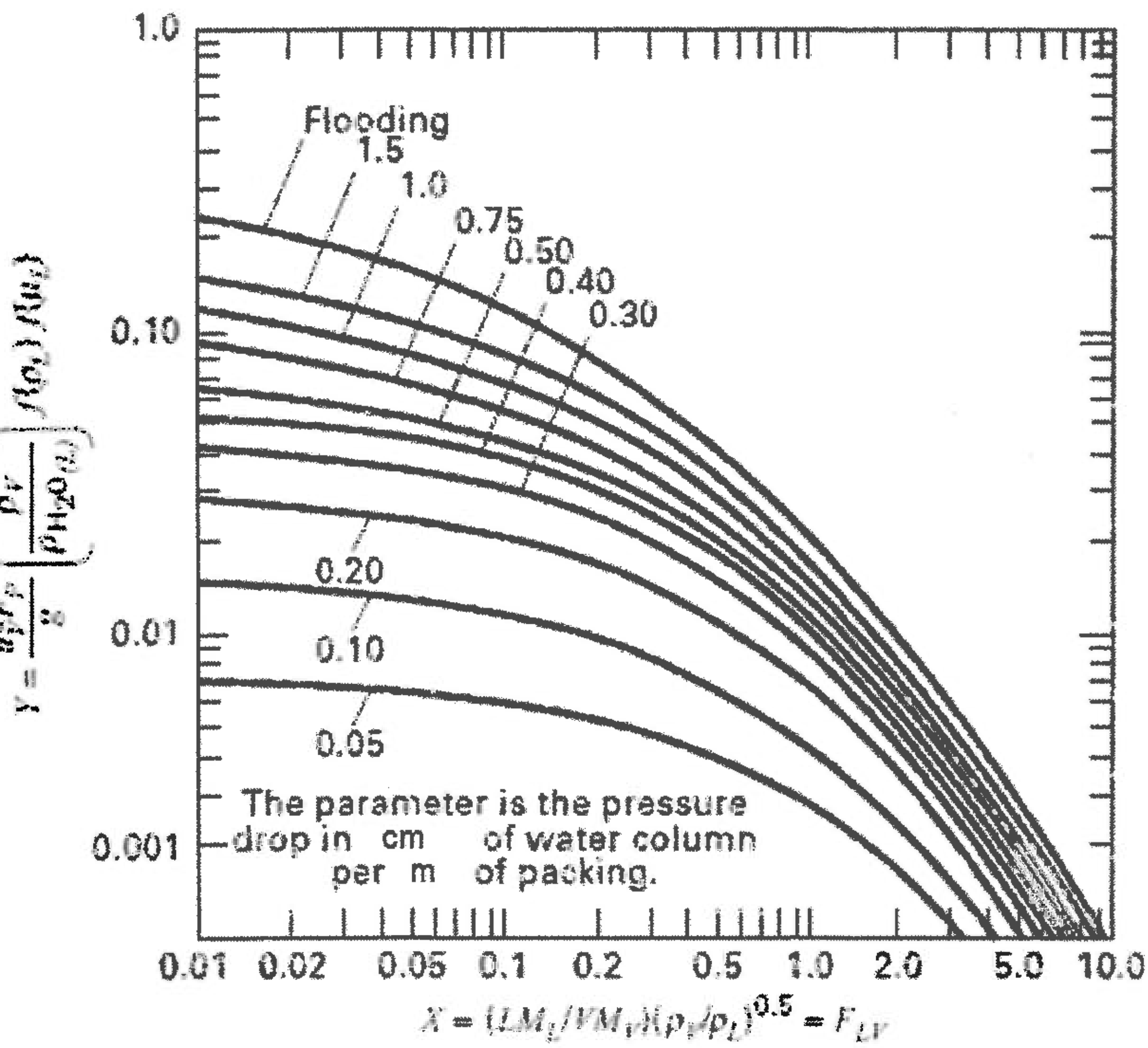

FIGURE 1: GPDC Chart

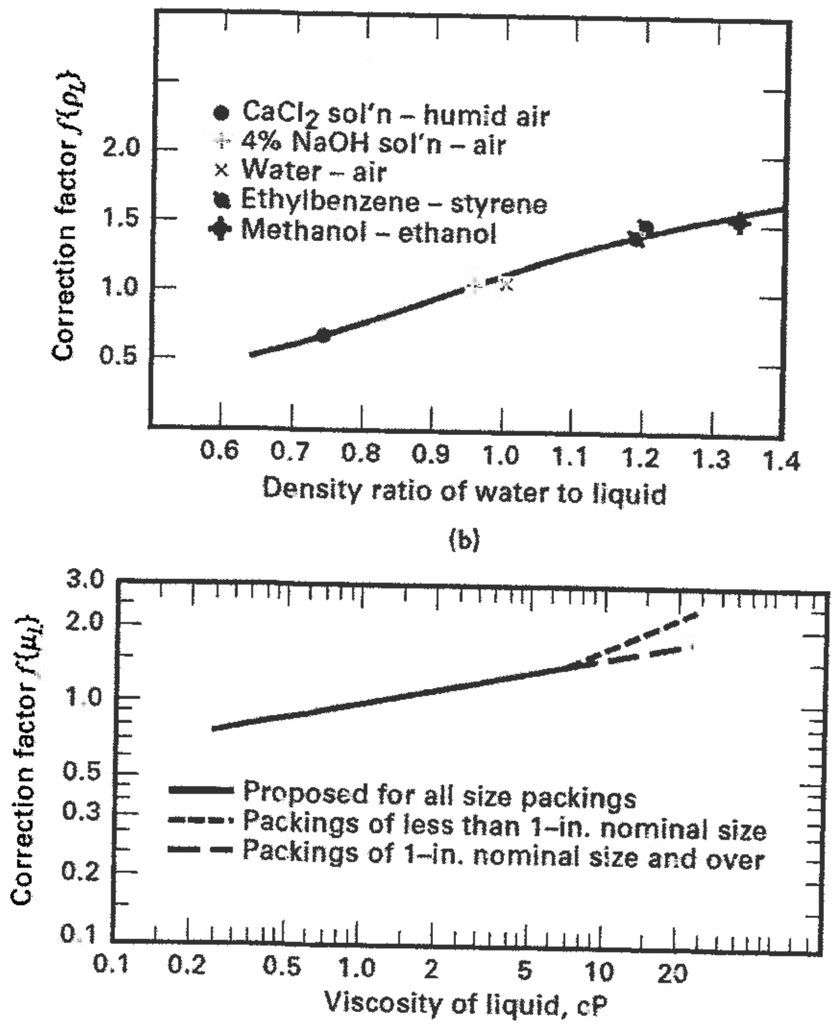

FIGURE 2: Correction Charts

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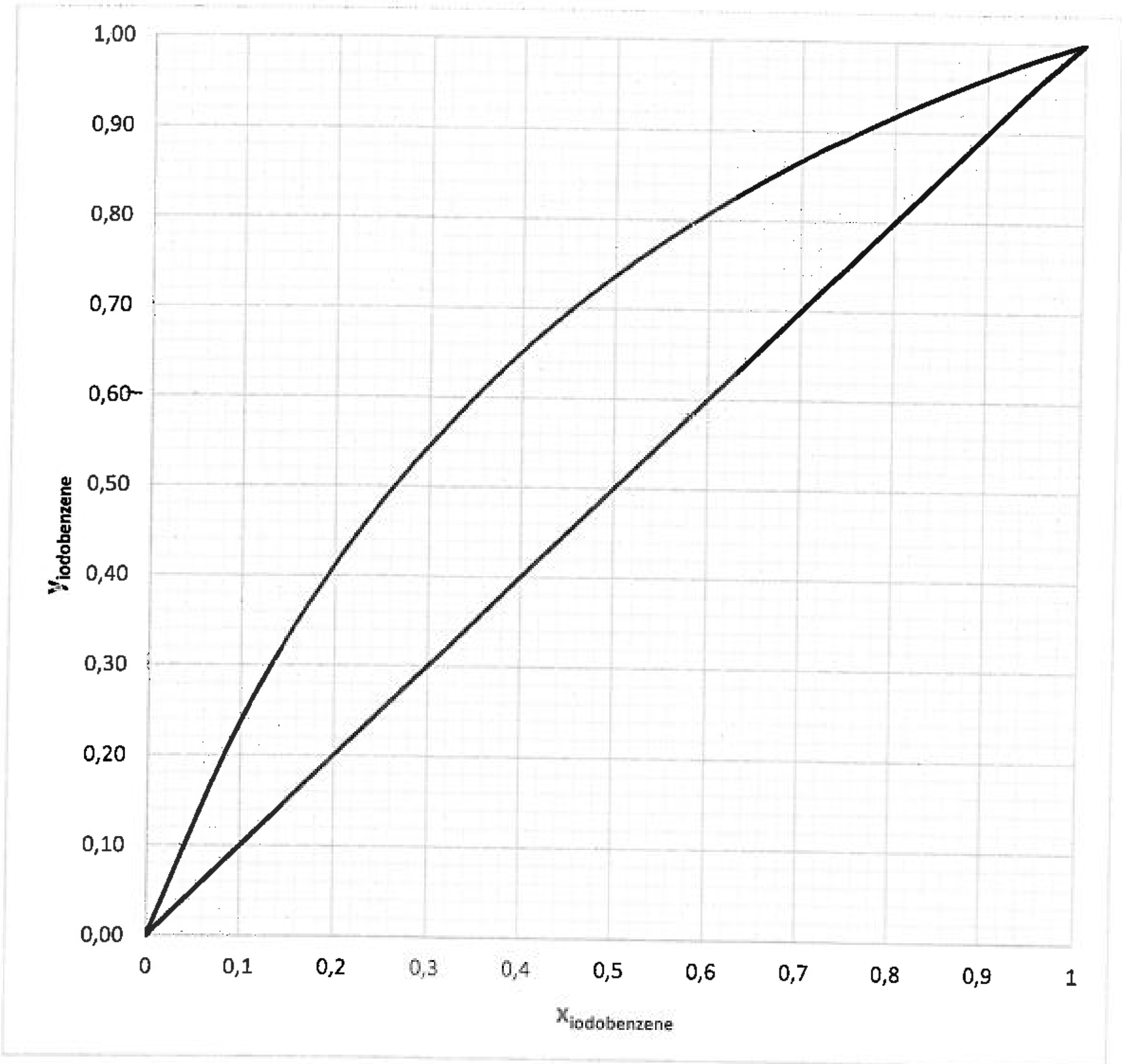

FIGURE 3: Equilibrium Data for Iodobenzene - Ethylene Glycol for Question 1

QUESTION 2

A flue gas stream from a pulverized coal combustion power plant flows at a rate of 1.5 m^3/s at 323 K and 101.3 kPa, and contains 6% by volume of sulphur dioxide (SO_2). SO_2 is a very hazardous gas which contributes to numerous respiratory problems and is acutely toxic. A new organic solvent, Dimethyl Sulphoxide (DMSO), is to be used as a solvent in an absorber to reduce emissions of SO_2. It is desired to remove 80% of the SO_2 in the absorber. The DMSO, after absorbing SO_2, is sent to a stripper where it is stripped of SO_2 by contact with pure steam at 1 atm and 373 K. The stream leaving the stripper that contains steam and SO_2 is then treated downstream. The DMSO leaving the stripper is cooled to 323 K and returned to the absorber.

Due to imperfect stripping and recycle, the DMSO entering the absorber contains 0.01 mole fraction of SO_2. A DMSO circulation rate of **1.5(L'_{min})** is recommended. In the stripper the steam rate is **1.3(V'_{min})**.

The DMSO-SO_2 solutions can be considered ideal and you may assume all gases and vapours behave as ideal gases.

Using the absorption and stripping equilibrium lines provided in **Figure 4** on **Page 6**, calculate:

a) The mass flow rate of DMSO required (kg/s). In addition, plot the operating line for absorption.

(13)

b) The mass flow rate of steam required (kg/s). Also, plot the operating line for stripping.

(10)

c) The composition of the vapour leaving the stripper in mole fraction.

(2)

MM_{DMSO} [$kg.kmol^{-1}$] = 78; MM_{H2O} = 18 [$kg.kmol^{-1}$]; Gas constant R = 8.314 [kJ/kmol.K]

DETACH PAGE 6 AND SUBMIT WITH ANSWER BOOK A.

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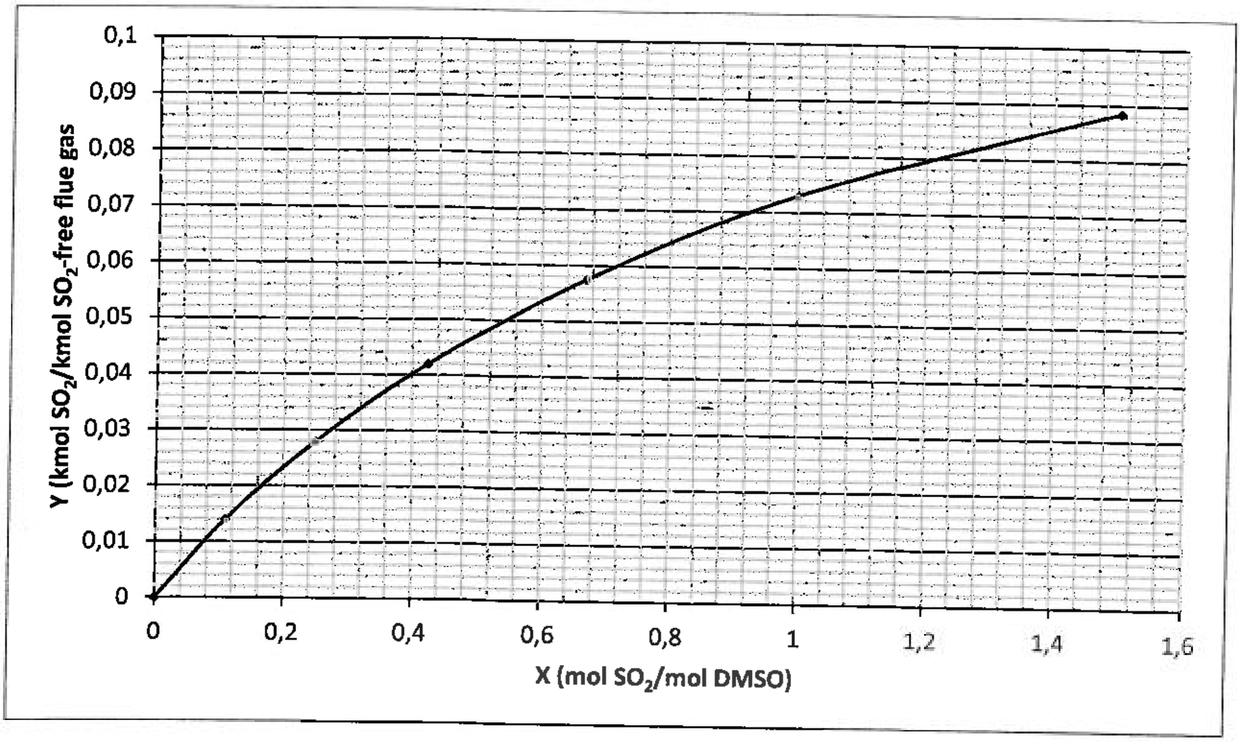

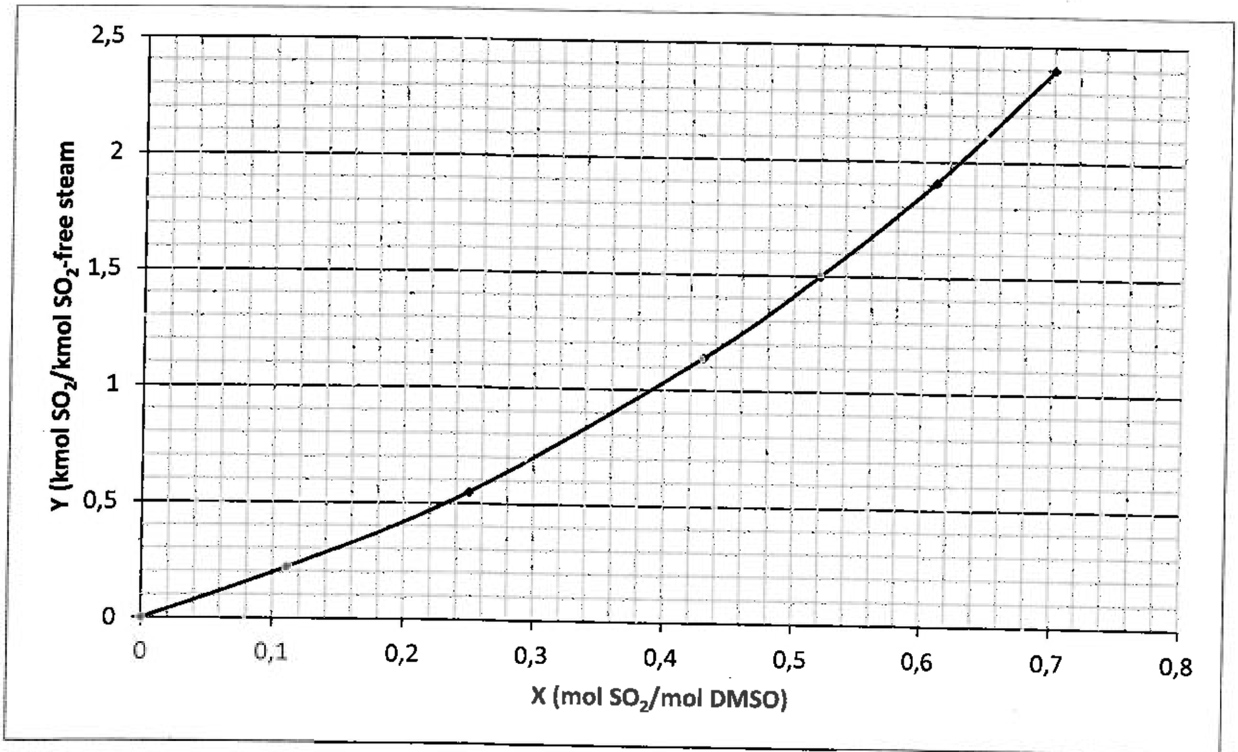

FIGURE 4: X-Y Plots for Question 2

SECTION B [ANSWER IN BOOK B]

QUESTION 3

a) List 7 factors to be considered during **real** solvent selection in liquid-liquid extraction.

(7)

b) List 8 factors to be considered during **ideal** solvent selection in liquid-liquid extraction.

(8)

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QUESTION 4

For the "solid-liquid" cascades shown in figure 5, obtain expressions for calculating X_N as a function of S, F_B, Washing Factor W and N separation stages.

Consider N-stage, counter current process:
F_A, F_B = mass flow rates of components A (insoluble) and B (soluble) in the feed
S = total mass flow rate of solvent, component C
Y_j = soluble material / (solute-free solvent) no solids [liquid overflow]
Underflow [FA; R; Xj]
R = mass of solvent/mass of insoluble solids [constant ratio]
X_j = soluble material/ (solute-free solvent) [underflow]
$X_j = Y_j$ equilibrium is achieved across each stage n
Washing factor is defined as $W=S/(RF_A)$.

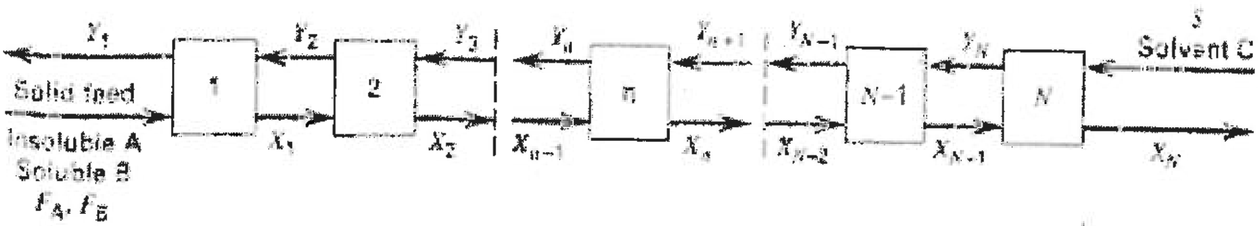

FIGURE 5

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QUESTION 5

From 2.000 kg/h of an acetic acid / water mixture with 45 wt% acetic acid, the acetic acid has to be extracted by a multi-step cross flow extraction at an operation temperature of 20 °C. The residual concentration of acetic acid has to be 10 wt% and the used solvent isopropyl ether is free of acetic acid.

Considering the following phase equilibrium data given in Table 2, determine:

a) The minimum amount of solvent for the first extraction step.

(5)

b) The necessary number of theoretical steps in the triangle diagram for the case that a solvent ratio of unity is chosen and in every step the same amount of solvent is added.

(20)

TABLE 2

extract phase			raffinate phase		
acetic acid	water	isopropyl ether	acetic acid	water	Isopropyl ether
0.002	0.005	0.993	0.007	0.981	0.012
0.004	0.007	0.989	0.014	0.971	0.015
0.008	0.008	0.984	0.029	0.955	0.016
0.019	0.010	0.971	0.064	0.917	0.019
0.048	0.019	0.933	0.133	0.844	0.023
0.114	0.039	0.847	0.255	0.711	0.034
0.216	0.069	0.715	0.367	0.589	0.044
0.311	0.108	0.581	0.443	0.451	0.106
0.362	0.151	0.487	0.464	0.371	0.165

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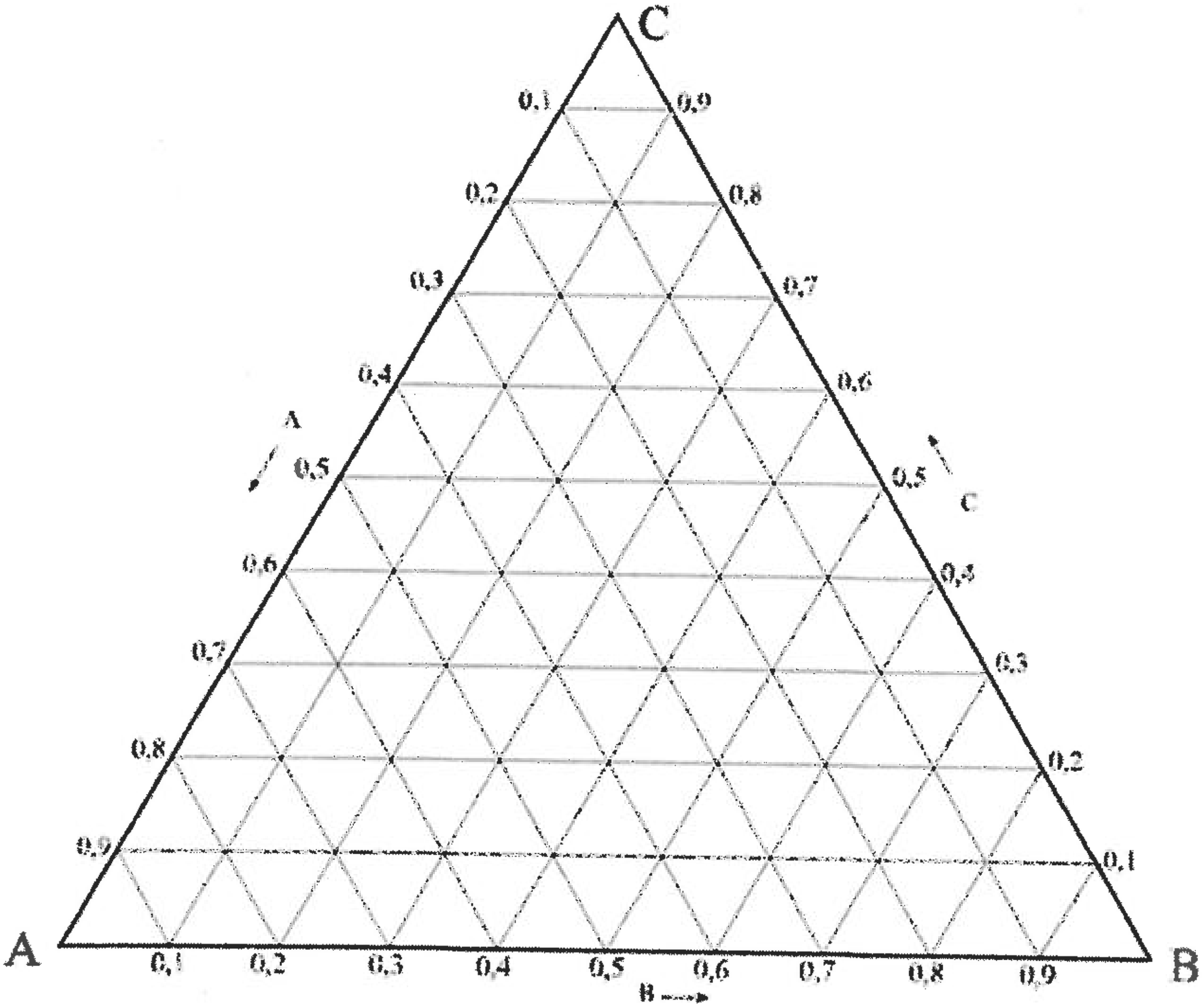

(A: Water; B: Isopropyl-ether; C: Acetic acid)

FIGURE 6

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SUPPLEMENTARY MATERIAL AND FORMULA 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: $q = \dfrac{\Delta H^{vap} + Cp_L(T_b - T_F)}{\Delta H^{vap}}$ $\qquad$ Superheated feed: $q = \dfrac{Cp_V(T_d - T_F)}{\Delta H^{vap}}$

Absorber and Stripper Equations:

$Y_{N+1} = X_N(L'/V') + Y_1 - X_0(L'/V')$ $\qquad$ $Y_N = X_{N+1}(L'/V') + Y_0 - X_1(L'/V')$

$y_n = Y_n/(1+Y_n)$ $\qquad$ $x_n = X_n/(1+X_n)$

Packed Absorbers:

Diameter of packed columns:

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