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INTERNAL MODERATOR:  ASSOCIATE PROF P NAIDOO

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 PAGE (7) IS DETACHED AND HANDED IN WITH ANSWER BOOK A.**

6. 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

Eighty (80) mol/s of a mixture of 40 mol% acetone (mwc) and 60 mol% acetonitrile is distilled using a column with a total of 19 theoretical stages, in order to separate the feed into a liquid distillate of 99 mol% acetone and a liquid bottoms product of 98 mol% acetonitrile. The pressure in the partial reboiler is 101 kPa. In the column pressure range, acetone and acetonitrile form ideal solutions and the relative volatilities at the bottom and top of the column are 2.27 (395 K) and 2.11 (360 K) respectively. The feed to the column is a mixture of vapour and liquid: 32.4 mol% of the feed is vapourised. The reflux ratio of the column is 1.5. A total condenser is to be used.

Determine algebraically:

a) The mole fraction of the liquid from the top stage of the column (stage 1). (3)

b) The liquid and vapour flow rates in the column, above and below the feed, and boilup ratio (V[B]). (9)

c) The mole fraction of the liquid from the bottom stage of the column (stage 18). (3)

d) Using an average temperature of 377.5 K and an arithmetic average relative volatility, find the overall tray efficiency using the O’Connell correlation, and determine the actual number of trays if the liquid column diameter is such that the liquid flow path is 4 ft. (7)

e) The vapour and liquid mole fraction at which the feed line and rectifying section operating line intersect. (3)

f) Using an arithmetic average relative volatility, calculate the total height of the packing required (in ft) for the first five (5) stages of the rectifying section of the column using the HETP method. (10)

H₀ (Rectifying section) = 1.16 ft; H₇ (Rectifying section) = 0.48 ft;

Reid et al. 1987

\[ \mu_L = \mu_A^x \mu_B^y \]

Correlation

\[ \ln \mu = A + B/T + CT + DT^2 \]

\[ \mu [cP]; T [K] \]

E₀ = 50.3(αμ)⁻⁰·₂²₆

<table>
<thead>
<tr>
<th>Component</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Dx10⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>4.612</td>
<td>148.9</td>
<td>-0.0254</td>
<td>2.222</td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>-5.878</td>
<td>1287</td>
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</table>

TOTAL /35/
QUESTION 2

A key issue in the treatment of groundwater is the removal of harmful volatile organic compounds such as cyclohexane. In a groundwater treatment plant, 0.006 kmol/s of water (solute free basis) contains 0.612 kmol cyclohexane/kmol water. It is desired to remove at least 90% of the cyclohexane using a stripping column, with open air being used as an abundant cost effective stripping agent. The actual flow rate of air is 1.5(V’min).

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

Using the stripping equilibrium line provided on page 7, determine:

a) The mass flow rate of air required (kmol/s). Also, plot the stripping operating line for stripping under minimum flow conditions

\[ \text{(10)} \]

b) The mole fraction of the vapour leaving the stripper, and the number of theoretical stages required.

\[ \text{(5)} \]

TOTAL /15/
SECTION B [ANSWER IN BOOK B]

QUESTION 3

A binary mixture of benzene (A) and toluene (B), containing 40% of benzene (by mole), is to be distilled at atmospheric pressure to recover 95% of the benzene. Consider a basis of 1 mole of feed and average relative volatility of benzene as 2.5.

Estimate the composition (in mole percent) of the residual mixture to be distilled and the composition of the distillate obtained if distillation is carried out by differential distillation, collecting all the distillate together using methods a and b.

a) Using material balance and considering the mixture to have constant relative volatility.

The following equation is to be used to find the number of moles present in the residue to the moles present initially in the feed:

\[ \frac{n_B}{n_{0B}} = (\frac{n_A}{n_{0A}})^{\frac{1}{\alpha}} \]

where \( n \) represents number of moles and \( \alpha \) stands for relative volatility.

\[(8)\]

b) Use Rayleigh's equation for differential distillation:

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

In the above equation, \( F \) is feed; \( W \) is residue; \( x_F \) is composition of feed; \( x_W \) is composition of residue; and \( \alpha \) is relative volatility.

\[(7)\]

TOTAL /15/
QUESTION 4

Penicillin F is recovered from a dilute aqueous fermentation broth by extraction with amyl acetate, using 6 volumes of solvent (V) per 100 volume of the aqueous phase (L). The distribution coefficient $K_D$ is 80.

a) What fraction of the penicillin would be recovered in a single ideal stage? (8)

b) Calculate the recovery using a two-stage extraction with fresh solvent entering in both stages. (12)

TOTAL /20/

QUESTION 5

2.5 m$^3$ of a wastewater solution with 0.25 kg phenol.m$^{-3}$ is mixed in an adsorption unit with 3 kg granular activated carbon until equilibrium is reached. Using the values from following table determined in the lab.

a) Calculate the isotherm parameters using the Langmuir equation: $C_{A,S} = (K_1 C_A)/(K_2 + C_A)$ where $C_{A,S}$ and $C_A$ are concentrations of phenol (A) on granular activated carbon and in wastewater solution, respectively. $K_1$ and $K_2$ are the Langmuir parameters. (3)

b) Calculate the steady-state conditions in the adsorber for $C_A$ in g.cm$^{-3}$ and for $C_{A,S}$ in grams solute per gram of activated carbon. (10)

c) Calculate the percentage amount of phenol that is recovered by the adsorbent. (2)

<table>
<thead>
<tr>
<th>$C_A$ (g.cm$^{-3}$)</th>
<th>$C_{A,S}$ (grams solute per gram of activated carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.004</td>
<td>0.026</td>
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<tr>
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<tr>
<td>0.195</td>
<td>0.129</td>
</tr>
</tbody>
</table>

TOTAL /15/
SUPPLEMENTARY MATERIAL AND DATA SHEET

McCabe-Thiele Analysis of Binary Distillation:

Equilibrium line: \[ y = \frac{\alpha x}{1 + (\alpha - 1)x} \quad x = \frac{y}{\alpha - (\alpha - 1)y} \]

Reflux Ratio: \( R = \frac{L}{D} \); \quad Boil-up Ratio: \( V_B = \frac{\bar{V}}{B} \)

Operating Lines:

- top: \( y = \left( \frac{R}{R + 1} \right) x + \frac{X_D}{R + 1} \)
- bottom: \( y = \left( \frac{V_B + 1}{V_B} \right) x - \frac{X_B}{V_B} \)

\( q \)-line:

\[ q = \frac{H_{F, sat, vap} - H_{F, feed}}{H_{F, sat, vap} - H_{F, sat, liq}} \]

for partially vapourised feed (0<q<1): \( q = \frac{L_F}{F} \)

\[ y = \left( \frac{q}{q - 1} \right) x - \left( \frac{x_F}{q - 1} \right) \]

\( \bar{L} - L = qF \)

\( \bar{V} - V = (q - 1)F \)

Subcooled feed: \( q = \frac{\Delta H_{vap} + c_p \Delta T_{vap}}{\Delta H_{vap}} \)

Superheated feed: \( q = \frac{c_p(T_d - T_F)}{\Delta H_{vap}} \)

Murphree Stage Efficiency:

\[ E_{MV} = \frac{y'_{n} - y'_{n+1}}{y'_{n} - y'_{n+1}} \]

Mass Transfer Equations for Packed Distillation Columns:

\( \lambda = m V / L \)

where \( m = dy/dx = \) slope of equilibrium curve

\( H_{00} = H_0 + \lambda H_0 \)

\[ HETP = H_{00} \ln \frac{\lambda}{\lambda - 1} \]
Stage-wise and Packed Bed Absorbers

Absorption Factor: \( A = \frac{L}{K \cdot V} \); Stripping Factor: \( S = \frac{KV}{L} \)

Mass transfer coefficients:

\[
\frac{1}{K \cdot a} = \frac{1}{k \cdot a} + \frac{K}{k \cdot a}
\]

Packed Absorbers:

Diameter of packed columns:

\[
D_T = \left[ \frac{4VM_V}{fU_f \pi \rho_f} \right]^{0.5}
\]

where \( V \) is in [kmol/s]

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

\[
l_T = \frac{V}{S} \int_{y_{out}}^{y_{in}} \frac{dy}{K \cdot a(y - y^*)^2(1 - y)^2} = H_{OG} N_{OG}
\]

Dilute systems with linear equilibrium

\[
l_T = \frac{V}{K \cdot a S} \int_{y_{out}}^{y_{in}} \frac{dy}{(y - y^*)}
\]

\[
N_{OG} = \frac{\ln \left( \frac{(A-1)(y_{in} - Ky_{in})}{y_{out} - Ky_{out}} + 1 \right)}{A}
\]

\[
(A - 1) / A
\]
DETACH THIS PAGE AND SUBMIT WITH ANSWER BOOK A

STUDENT NUMBER: ____________________________