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|---|---|---|
| **PROGRAM** | : | BACHELOR OF ENGINEERING TECHNOLOGY<br>*CHEMICAL ENGINEERING* |
| **SUBJECT** | : | **MULTISTAGE OPERATIONS 3A** |
| **CODE** | : | **MSOCHA3** |
| **DATE** | : | WINTER EXAMINATION<br>04 JUNE 2019 |
| **DURATION** | : | (SESSION 2) 12:30 - 15:30 |
| **WEIGHT** | : | 40 : 60 |
| **TOTAL MARKS** | : | 100 |

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|---|---|---|
| **EXAMINER(S)** | : | Mr G PAHLA and PROF K MOOTHI |
| **MODERATOR** | : | Prof G SIMATE |
| **NUMBER OF PAGES** | : | 06 PAGES |

**REQUIREMENTS** : 2 Sheets Graph Paper

**HINTS AND INSTRUCTIONS TO CANDIDATE(S):**

- **Purpose of this assessment is to determine whether you can analyse a broadly-defined problem, identify relevant engineering principles and apply them to solve the problem. Set out your solutions in a logical and concise manner with justification for the steps that you follow.**
- **ATTEMPT ALL QUESTIONS**. Please answer each question to the best of your ability.
- Write your details (module name and code, ID number,student number etc.)on script(s).
- Number each question clearly; questions may be answered in any order.
- Make sure that you read each question carefully before attempting to answer the question.
- Show all steps (and units) in calculations; this is a 'closed book' test.
- Ensure your responses are legible, clear and include relevant units (where appropriate).

**Question One: 33 Marks [*This question assesses Graduate Attribute 1. It is compulsory]***

You are required to design a fractionating column for the separation of a liquid mixture containing; 40 kmol hexane, 35 kmol heptane and 25 kmol octane. The hydrocarbon mixture is at its bubble point. The operation should recover 97.15 % of heptane in the distillate and the percentage of octane in the bottom stream should be 96 %. If the feed flow rate is 100 kmol per hour and the column is to operate at 70 % overall efficiency, estimate the actual number of equilibrium plates required. $R = 1.4\ R_{min}$

The average relative volatilities with respect to Octane are; 2.70 and 2.22 respectively.

**Question Two** **[Total: 20 Marks]**

100 kmol/h of a gas mixture containing 85 mol% $CH_4$, 6% $C_2H_6$, 5% $C_3H_8$ and 4% n-$C_4H_{10}$ is fed to a absorption tower operating at 37$^oC$ and 6 000 kPa. 80% of $C_3H_8$ has to be removed from the gas mixture using Lean oil. The oil composition is 0,5 mol% $C_4H_{10}$ and it is non-volatile under these conditions. Given that the flow ratio of inlet gas to lean oil is 0.5, determine the flowrate of $C_1$ and $C_4$ in the exit streams

K values are as follows: $CH_4$ = 32; $C_2H_6$ = 6,7; $C_3H_8$ = 2,4; n ± $C_4H_{10}$ = 0,74.

**Question Three** **[Total: 15 Marks]**

A solution containing 23 mass % $Na_3PO_4$ is cooled from 313 K to 298 K in a Swenson-Walker crystalliser to form crystals of $Na_3PO_4.12\ H_2O$. The solubility of $Na_3PO_4$ at 298 K is 15,5 kg/100 kg water. Calculate the crystal yield per 1 kg of feed.

[Molar Mass: Na = 23 g/mol, P = 31 g/mol]

**Question Four: 32 Marks [*This question assesses Graduate Attribute 1. It is compulsory]***

Acetone is to be recovered from a 50 wt% aqueous solution using multistage cross-current extraction with trichloroethane (TCA) as the solvent. The feed is 500 kg/h and the final rafinate should contain not more than 9 wt% Acetone. 200 kg of solvent containing 2% Acetone is added to each stage. The Equilibrium data is given in Table 1.

Table 1: Equilibrium Data

| **Raffinate arm (mass fraction)** | | | **Extract arm (mass fraction)** | | |
|---|---|---|---|---|---|
| $x_c$ | $x_A$ | $x_B$ | $y_c$ | $y_A$ | $y_B$ |
| 0.55 | 0.35 | 0.10 | 0.60 | 0.13 | 0.27 |
| 0.50 | 0.43 | 0.07 | 0.50 | 0.04 | 0.46 |
| 0.40 | 0.57 | 0.03 | 0.40 | 0.03 | 0.57 |
| 0.30 | 0.68 | 0.02 | 0.30 | 0.02 | 0.68 |
| 0.20 | 0.79 | 0.01 | 0.20 | 0.015 | 0.785 |
| 0.10 | 0.895 | 0.005 | 0.10 | 0.01 | 0.89 |

| Tie Line Data | |
|---|---|
| **Raffinate** | **Extract** |
| 0.12 | 0.18 |
| 0.29 | 0.40 |
| 0.44 | 0.56 |

**4.1.** Determine the required number of equilibrium stages. **[25]**

**4.2**. Determine the total amount of Acetone extracted. **[7]**

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**END** **[Total: 100 Marks]**

**USEFUL EQUATIONS AND FORMULAE**

<u>McCabe-Thiele Method</u>: $y_1 = \dfrac{\alpha_{1,2}\,(x_1)}{1+(x_1)(\alpha_{1,2}-1)}$

$$y_q = \frac{q}{q-1}x_q - \frac{z_f}{q-1}$$

<u>Fenske's Equation(s)</u>:

$$N_{\min}+1 = \frac{\log\left[\left(\frac{x_{LK}}{x_{HK}}\right)_D\left(\frac{x_{HK}}{x_{LK}}\right)_B\right]}{\log \alpha_{LK,HK}}, \quad b_i = \frac{f_i}{1+\left(d_r/b_r\right)(\alpha_{i,r})_m^{N_{\min}}}, \quad d_i = \frac{f_i\left(d_r/b_r\right)(\alpha_{i,r})_m^{N_{\min}}}{1+\left(d_r/b_r\right)(\alpha,r)_m^{N_{\min}}}$$

<u>Minimum Reflux Ratio by Underwood's Equation(s)</u>:

$$\sum\frac{\alpha_i x_{iD}}{\alpha-\theta} = R_m+1 \qquad \alpha_{HK}<\theta<\alpha_{LK}$$

$$\sum\frac{\alpha_i x_{iF}}{\alpha-\theta} = 1-q$$

<u>Feed Plate Location by Kirkbride's Equation(s)</u>:

$$\log\left[\frac{N_r}{N_s}\right] = 0.026\log\left[\frac{W}{D}\left(\frac{x_{HK}}{x_{LK}}\right)_F\left(\frac{x_{LKW}}{x_{HKD}}\right)^2\right], \qquad \frac{N_R}{N_S} = \left[\left(\frac{Z_{j,F}}{Z_{i,F}}\right)\left(\frac{x_{i,B}}{x_{j,D}}\right)^2\left(\frac{B}{D}\right)\right]^{0.206}$$

<u>Erbar-Maddox correlation</u>: $\frac{R}{R+1}$ vs $\frac{N_m}{N}$ with $\frac{R_m}{R_m+1}$ as a parameter

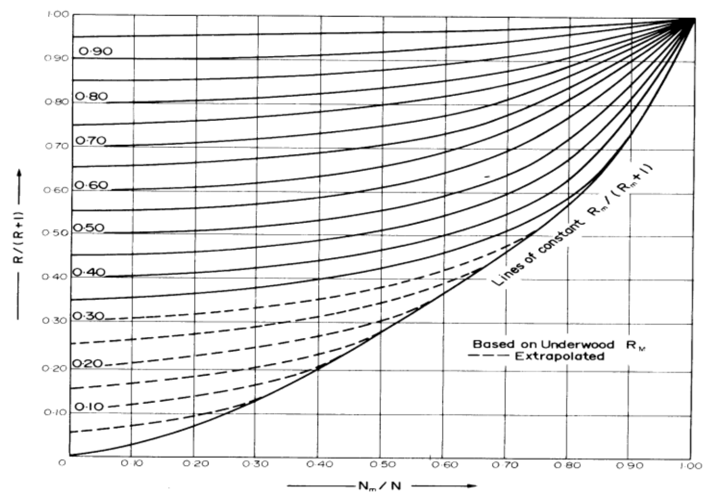


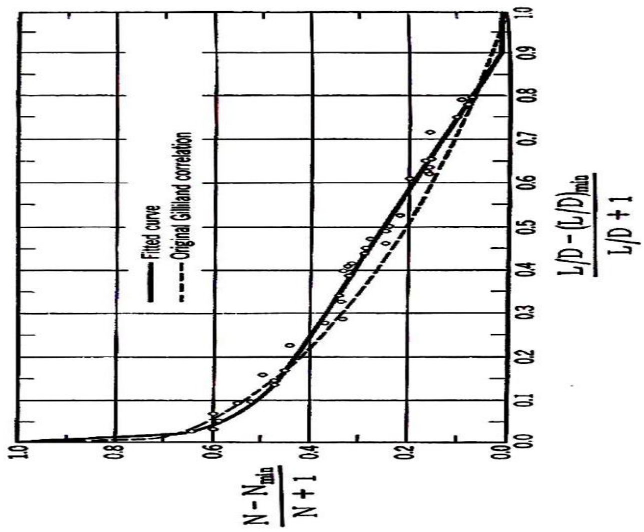

FIG. 11.11. Erbar–Maddox correlation (Erbar and Maddox, 1961)

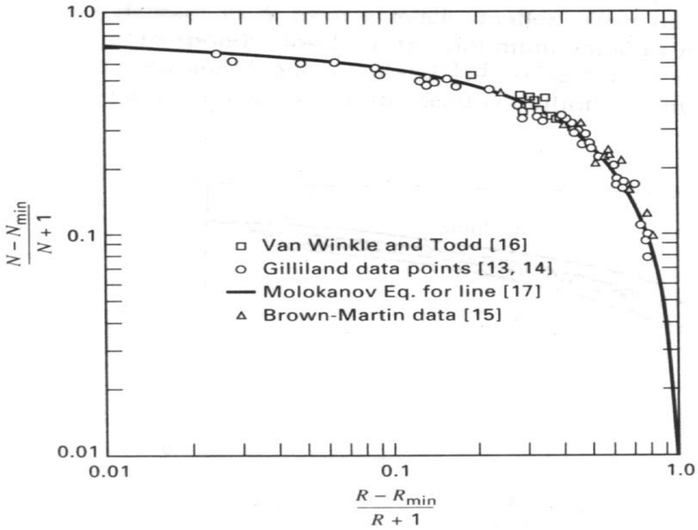
<u>Bubble and Dew point calculation(s)</u>:

$$\sum y_i = \sum K_i x_i = K_c\sum \alpha_i x_i = 1.0, \quad y_i = \frac{\alpha_i x_i}{\sum(\alpha_i x_1)}, \quad \sum_{i=1}^{N_C} y_1 = \sum_{i=1}^{N_C} K_i x_i = 1.0, \quad (K_p)Trial2 = \frac{(K_p)Trial1}{\sum K_i x_i}$$

$$\sum x_i = \sum\left(\frac{y_i}{K_i}\right) = \left(\frac{1}{K_C}\right)\sum\left(\frac{y_i}{\alpha_1}\right) = 0, \quad x_i = \frac{y_i/x_i}{\sum\left(y_i/x_i\right)}, \quad \sum_{i=1}^{N_C} x_i = \sum_{i=1}^{N_C}\frac{y_i}{K_i} = 1.0, \quad (K_i)Trial2 = (K_i)Trial1\sum\frac{y_i}{K_i}$$

Gilliland correlation (number of ideal plates at the operating reflux):




Molokanov's Correlation:

$$\frac{N-N_{\min}}{N+1}=1-\exp\left[\left(\frac{1+54.4\Psi}{11+117{,}2\Psi}\right)\left(\frac{\psi-1}{\psi^{0.5}}\right)\right]$$

Where: $\Psi\equiv\frac{R-R_{\min}}{R+1}$ ; $R_m=\frac{1}{\alpha-1}\left[\frac{x_d}{x_f}-\alpha\frac{1-x_d}{1-x_f}\right]$

Slope of q-line: $-\left(\frac{f}{1-f}\right)$ ; $f=\left(\frac{c_p(t_b-t_f)_{Liquid}+\Lambda_{Feed}+(c_p(t_b-t_f))_{\text{sup}erneated\ vapour}}{\Lambda}\right)$

Number of transfer units is given by: $N_{OG}=\int_{Y_1}^{Y_2}\frac{dY}{Y_e-Y}$ ; $N_{OG}=\frac{Z}{H_{OG}}$ ; $N_{OL}=N_{OG}\left(\frac{mG_M}{L_M}\right)$

Height of transfer unit is given by: $H_{OG}=\frac{G_M}{K_G aP}$

Equilibrium partial pressure: $P_a=P_a^o\left\{\frac{n_a}{n_a+n_b+n_c+\ldots\ldots\ldots\ldots}\right\}=x_aP_a^o$

<u>Water balance:</u> $w_1 = w_2 + \left(y - \frac{y}{R}\right) + w_1 E$

<u>Yield of crystals:</u> $y = \frac{R w_1 [c_1 - c_2(1-E)]}{[1 - c_2(R-1)]}$

Adsorption Isotherms:

$q = Kc^n$ , $q = \frac{q_o\, c}{K + c}$ ,

**Table A.1: Conversion Factors**

| Quantity | Conversion |
|---|---|
| Length | 1 m = 100 cm<br>= 3.28084(ft) = 39.3701(in) |
| Mass | 1 kg = $10^3$ g<br>= 2.20462($lb_m$) |
| Force | 1 N = 1 kg m $s^{-2}$<br>= $10^5$(dyne)<br>= 0.224809($lb_f$) |
| Pressure | 1 bar = $10^5$ kg $m^{-1}$ $s^{-2}$ = $10^5$ N $m^{-2}$<br>= $10^5$ Pa = $10^2$ kPa<br>= $10^6$(dyne) $cm^{-2}$<br>= 0.986923(atm)<br>= 14.5038(psia)<br>= 750.061(torr) |
| Volume | 1 $m^3$ = $10^6$ $cm^3$ = $10^3$ liters<br>= 35.3147$(ft)^3$<br>= 264.172(gal) |
| Density | 1 g $cm^{-3}$ = $10^3$ kg $m^{-3}$<br>= 62.4278($lb_m$)$(ft)^{-3}$ |
| Energy | 1 J = 1 kg $m^2$ $s^{-2}$ = 1 N m<br>= 1 $m^3$ Pa = $10^{-5}$ $m^3$ bar = 10 $cm^3$ bar<br>= 9.86923 $cm^3$(atm)<br>= $10^7$(dyne) cm = $10^7$(erg)<br>= 0.239006(cal)<br>= 5.12197 × $10^{-3}$$(ft)^3$(psia) = 0.737562(ft)($lb_f$)<br>= 9.47831 × $10^{-4}$(Btu) = 2.77778 × $10^{-7}$ kWhr |
| Power | 1 kW = $10^3$ W = $10^3$ kg $m^2$ $s^{-3}$ = $10^3$ J $s^{-1}$<br>= 239.006(cal) $s^{-1}$<br>= 737.562(ft)($lb_f$) $s^{-1}$<br>= 0.947831(Btu) $s^{-1}$<br>= 1.34102(hp) |

**Table A.2: Values of the Universal Gas Constant**

$R$ = 8.314 J $mol^{-1}$ $K^{-1}$ = 8.314 $m^3$ Pa $mol^{-1}$ $K^{-1}$
= 83.14 $cm^3$ bar $mol^{-1}$ $K^{-1}$ = 8,314 $cm^3$ kPa $mol^{-1}$ $K^{-1}$
= 82.06 $cm^3$(atm) $mol^{-1}$ $K^{-1}$ = 62,356 $cm^3$(torr) $mol^{-1}$ $K^{-1}$
= 1.987(cal) $mol^{-1}$ $K^{-1}$ = 1.986(Btu)(lb mole)$^{-1}$(R)$^{-1}$
= 0.7302$(ft)^3$(atm)(lb mol)$^{-1}$(R)$^{-1}$ = 10.73$(ft)^3$(psia)(lb mol)$^{-1}$(R)$^{-1}$
= 1,545(ft)($lb_f$)(lb mol)$^{-1}$(R)$^{-1}$