PROGRAM	:	BACCALAUREUS TECHNOLGIAE
		CHEMICAL ENGINEERING
SUBJECT	:	**UNIT OPERATIONS IV**
CODE	:	**WARB432**
DATE	:	WINTER EXAMINATION
		29 MAY 2019
DURATION	:	SESSION 1(08:30 – 11:30)
WEIGHT	:	40 : 60
TOTAL MARKS	:	100
EXAMINER(S)	:	MR G PAHLA
MODERATOR	:	DR I AMER
NUMBER OF PAGES	:	07 PAGES
REQUIREMENTS	:	2 Sheets of Graph Paper

HINTS AND INSTRUCTIONS TO CANDIDATE(S):

- Purpose of assessment is to determine not only if you can write down an answer, but also to assess whether you understand the concepts, principles and expressions involved. Set out solutions in a logical and concise manner with justification for the steps followed.
- **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 (Multi-component Distillation) [Total: 30 Marks]

A distillation column is used to separate a hydrocarbon mixture containing 25% C_2, 30% C_3, 30% nC_4 and 15% nC_5. The aim is to recover 96% of C_4 in the bottom stream. It can be assumed that all C_2 reports to the distillate and the mole fraction of C_3 in the bottom stream is 0.005. The feed is at its dew point and its flow rate is 1200 kmol/hr. The column operates at 4.5 bar, 25^0C and $1.3R_m$. The relative volatilities with respect to nC_4 are 10.69, 3.466, 1 and 0.31.
Use the shortcut design method (Fenseke – Underwoood – Gilliland) to estimate the actual number of trays at 75 % overall efficiency.

Question Two (Liquid –Liquid Extraction) [Total: 30 Marks]

A counter-current solvent extraction system is used to treat 500 kg/h of a 40%wt mixture of DPH in Docosane. The aim is to recover the DPH until the final raffinate only contains 5%wt DPH. It is suggested to use 500 kg/h of solvent containing 98% wt of Furfural and 2% DPH. The equilibrium and tie-line data is given below.

Equilibrium data (mass%)													
A	96.0	84.0	67.0	52.5	32.6	21.3	13.2	7.7	4.4	2.6	1.5	1.0	0.7
B	4.0	5.0	7.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	99.3
C	0	11.0	26.0	37.5	47.4	48.7	46.8	42.3	35.6	27.4	18.5	9.0	0.0

Tie-line data					
Raffinate (Docosane) phase, mass%			Extract (Furfural) phase, mass%		
A	*B*	*C*	*A*	*B*	*C*
85.2	4.8	10.0	1.1	89.1	9.8
69.0	6.5	24.5	2.2	73.6	24.2
43.9	13.3	42.6	6.8	52.3	40.9

2.1. Using the right angle diagram, determine the number of theoretical stages required. **[25]**

2.2. Determine the amount of the raffinate and extract phases exiting the counter current extraction cascade. **[5]**

Question Three (Multicomponent Absorption) [Total: 15 Marks]

A mixture of alkanes is to be separated by continuous counter-current absorption in a non-volatile oil. The feed flow is 1000 kmol/hr and the ratio of solvent to untreated vapour is 2.5 kmol solvent/1kmol vapour. The feed composition and K –values are given in the Table below. The pressure is 3 bar, and the temperature is 200 °C. It is desired to recover 90% of the n –butane in the liquid. Find the number of theoretical stages, and the gas and liquid outlet compositions for C_1.

Component	Mol%	K
CH_4	80	46
C_2H_6	4	8.1
C_3H_8	6	2.8
n-C_4H_{10}	3	0.7
n-C_5H_{12}	0.3	0.22

Question Four (Crystallization) [Total: 15 Marks]

A feed solution of 2268 kg at 328 K that contains 48,2 kg $MgSO_4$/100 kg water is cooled to 293 K where $MgSO_4$. 7 H_2O crystals are removed. The solubility of the salt at 293 K is 35,5 kg $MgSO_4$/100 kg water. Calculate the yield of crystals assuming no water is vapourised.

4.1. Use mass balance. **[8]**
4.2. Use formulae. **[7]**

[Mw: Mg = 24g/mol., S = 32 g/mol]

Question Five (Fluidization) [Total: 10 Marks]

Non-spherical catalyst pellets, 4 mm in diameter, shape factor of 1.1, are to be fluidized with air at 101.3 kPa at 70 °C. The density of the catalyst particles is 1100 kg/m^3. Take the molecular weight of air as 26.9 kg/kmol.

If it is assumed that the point of incipient fluidization is reached at ε_{mf}=0.43 Calculate the pressure gradient at this point (incipient fluidization).

μ_{air} = 0.0000207 Ns/m^2.

END **[Total: 100 Marks]**

Useful Formulae and Correlations

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

$y_n = \dfrac{L_n}{V_n}x_{n+1} + \dfrac{D}{V_n}x_D$ or $y_n = \dfrac{R}{R+1}x_{n+1} + \dfrac{x_D}{R+1}$, $y_m = \dfrac{L_m}{V_m}x_{m+1} - \dfrac{B}{V_M}x_B$, $y_q = \dfrac{q}{q-1}x_q - \dfrac{z_f}{q-1}$

Fenske's Equation(s):

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

Minimum Reflux Ratio by Underwood's Equation(s):

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

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

Feed Plate Location by Kirkbride's Equation(s):

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

Erbar-Maddox correlation: $\dfrac{R}{R+1}$ vs $\dfrac{N_m}{N}$ with $\dfrac{R_m}{R_m+1}$ as a parameter

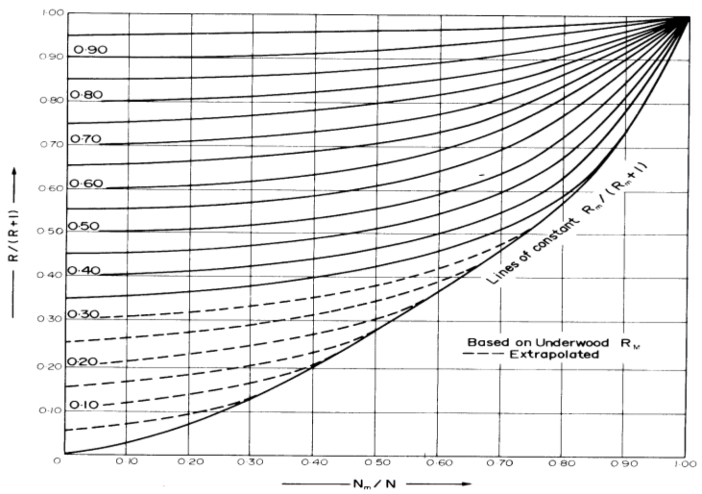


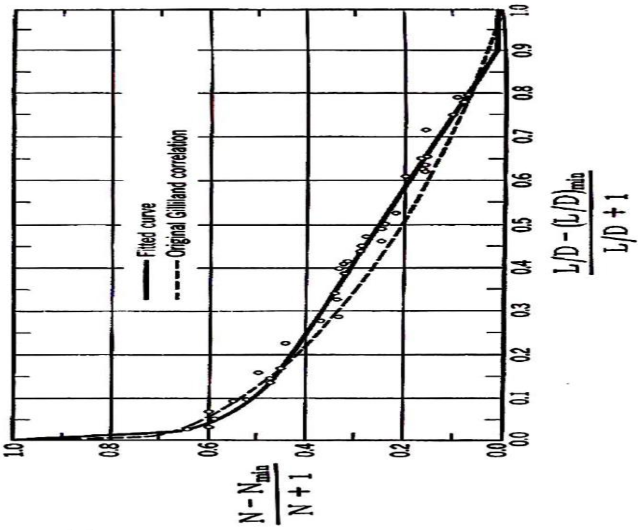
FIG. 11.11. Erbar–Maddox correlation (Erbar and Maddox, 1961)

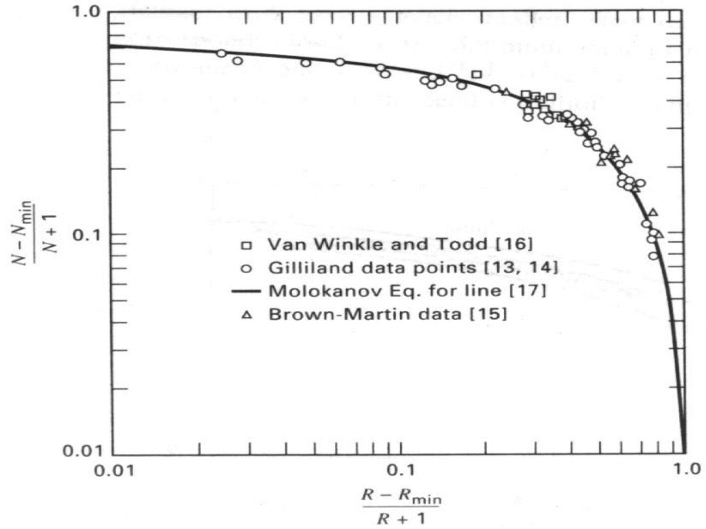
Bubble and Dew point calculation(s):

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

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

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





Molokanov's Correlation:

$$\frac{N - N_{\min}}{N+1} = 1 - \exp\left[\left(\frac{1+54.4\Psi}{11+117{,}2\Psi}\right)\left(\frac{\psi - 1}{\psi^{0.5}}\right)\right] \qquad \text{Where: } \Psi \equiv \frac{R - R_{\min}}{R+1}; \qquad R_m = \frac{1}{\alpha - 1}\left[\frac{x_d}{x_f} - \alpha\frac{1-x_d}{1-x_f}\right]$$

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

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: $H_{OG} = \frac{G_M}{K_G a P}$

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

$$\Delta T = T_{steam} - T_b$$

Heat balance: $$\{m_{steam} x h_{fg}\} = \{m_{feed} C_p \Delta T\} + \{m_v x h_{fg}\} + \{m_L C_p \Delta T\}$$

$$Q = m_{steam} h_{fg} = m_{feed} C_p \Delta T + m_v h_{fg}$$

$$Q = m_{feed} C_p \Delta T + m_{v1} h_{fg}$$

Start-up filter: $$\frac{t - t_s}{V - V_s} = \frac{K_1 (V + V_s)}{2P} + \frac{K_2}{P}$$

Rotary filter: $$\theta_f = k_f \theta_c \quad ; \quad \theta_f = \frac{K_1 V_f^2}{2P} + \frac{K_2 V_f}{P}$$

Ergun equation: $$-\frac{\Delta P}{L} = \frac{150(1-\varepsilon)^2}{\varepsilon^3} \frac{\mu . u_c}{d^2} + \frac{1.75(1-\varepsilon)}{\varepsilon^3} \frac{\rho . u_c^{\ 2}}{d} \; ; \qquad Ga = \frac{d^3 \rho (\rho_s - \rho) g}{\mu^2}$$

Pressure drop: $$(-\Delta P) = (1 - e_{mf})(\rho_s - \rho) lg \; ; \qquad Re_0' = (2.33 Ga^{0.018} - 1.53 Ga^{-0.016})^{13.3}$$

$$\frac{L_f}{L_p} = \frac{1 - e_p}{1 - e_f} \quad ; \quad (1 - e_{mf})(\rho_s - \rho) g = \frac{150 (1 - e_{mf})^2}{e_{mf}^3} \frac{\mu u_{mf}}{d^2} + \frac{1.75 (1 - e_{mf})}{e_{mf}^3} \frac{\rho u^2}{d}$$

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

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

$$\frac{1}{nF} \frac{V_W}{V_L} = \ln \frac{1 - F}{F}$$

Table A.1: Conversion Factors

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