



**PROGRAM** : BACHELOR OF ENGINEERING TECHNOLOGY  
*CHEMICAL ENGINEERING*

**SUBJECT** : **CHEMICAL ENGINEERING FUNDAMENTALS**

**CODE** : **CEFCHB1**

**DATE** : SUMMER EXAMINATION  
23 NOVEMBER 2019

**DURATION** : (SESSION 1) 08:30 - 11:30

**WEIGHT** : 40: 60

**TOTAL MARKS** : 92

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**EXAMINER(S)** : MR IM RAMATSA

**MODERATOR** : PROF K MOOTHI

**NUMBER OF PAGES** : 7PAGES

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**REQUIREMENTS** : Use of scientific (non-programmable) calculator is permitted

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**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****[TOTAL: 20 MARKS]**

**1.1** Wine making involves a series of very complex reactions most of which are performed by microorganisms. The starting concentration of sugars determines the final alcohol content and sweetness of the wine. The specific gravity of the starting stock is therefore adjusted to achieve desired quality of wine. A starting stock solution has a specific gravity of 1.075 and contains 12.7 wt% sugar. If all the sugar is assumed to be  $C_{12}H_{22}O_{11}$ , Determine

**1.1.1** kg sugar/kg  $H_2O$  (5)

**1.1.2** lb solution/ft<sup>3</sup> solution (5)

**1.1.3** g sugar/L solution (5)

**1.2** Covert the following expression to SI units (5)

$$\frac{6(in)(cm^2)}{(yr)(s)(lb_m)(ft^2)}$$

**QUESTION TWO****[TOTAL: 20 MARKS]**

To make strawberry jam, strawberries containing 15 wt% solids and 85 wt% water are crushed. The crushed strawberries and sugar are mixed in a 4/5 mass ratio and the mixture is heated to evaporate water. The residue contains one-third water by mass. Calculate the amounts of strawberries needed to make 100 g of jam, and of the evaporated water.

**2.1** Draw and label the process flowchart. (5)

**2.2** Perform the degree of freedom for this process. (2)

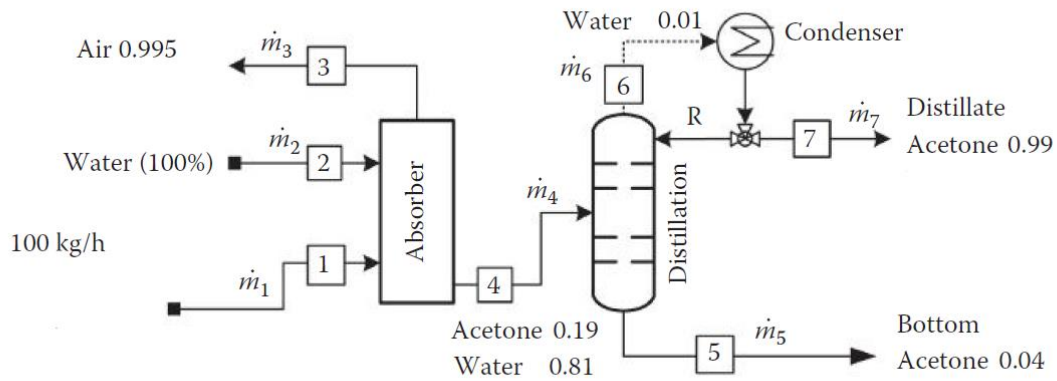
**2.3** Calculate the amounts of strawberries, composition of solids in 100 g jam and sugar needed to make 100 g of jam. (10)

**2.4** Calculate the amount of evaporated water. (3)

**QUESTION THREE****[TOTAL: 27 MARKS]**

Contaminated air containing 3% acetone and 2% water is fed to an absorber column as shown in the Figure below. The mass flow rate of air is 100 kg/h. Pure water is used as an absorbent to absorb acetone from air. The air leaving the absorber should be free of acetone and contain 0.5% water. The bottom liquid of the absorber is fed to a distillation column to separate acetone from water. The bottom stream of the distillation column was found to contain 4% acetone and the balance is water. The vapor from the overhead of the distillation column is totally condensed and split into two portions, one portion is recycled to the column and the second fraction forms the distillate product stream. The concentration of the condensate is found to be 99% acetone. All percentages are in weight percent.

- 3.1 Choose a basis (2)
- 3.2 Perform material balance and calculate mass flowrates  $\dot{m}_3$ ,  $\dot{m}_4$  and  $\dot{m}_2$  (9)
- 3.3 Calculate mass flowrate of the distillate and the bottom stream (9)



- 3.2 It is desired to achieve the same separation with a feed of 1250 kg/h. Scale the flowchart accordingly. (7)

#### QUESTION FOUR

[TOTAL: 15 MARKS]

A cylinder with a movable piston contains 4 liters of a gas at 30°C and 5 bar. The piston is slowly moved to compress the gas to 8 bar.

- 4.1 Considering the system to be the gas in the cylinder and neglecting  $\Delta E_p$ , write and simplify the closed-system energy balance. Do not assume that the process is isothermal in this part. (5)
- 4.2 Suppose now that the process is carried out isothermally, and the compression work done on the gas equals 7.65 L·bar. If the gas is ideal so that  $\hat{U}$  is a function only of T, how much heat (in joules) is transferred to or from (state which) the surroundings? (Use the gas-constant table in the appendix to determine the factor needed to convert L·bar to joules.) (5)
- 4.3 Suppose instead that the process is adiabatic and that  $\Delta \hat{U}$  increases as T increases. Is the final system temperature greater than, equal to, or less than 30°C? (Briefly state your reasoning.) (5)

**QUESTION FIVE****[TOTAL: 10 MARKS]**

The standard heat of reaction for the combustion of liquid n-nonane to form  $CO_2$  and liquid water at 25°C and 1 atm is  $\Delta \hat{H}_r^o = -6124 \text{ kJ/mol}$ .

- 5.1** Briefly explain what the given information means. (3)
- 5.2** Is the reaction exothermic or endothermic at 25°C? (1)
- 5.3** Would you have to heat or cool the reactor to keep the temperature constant? (2)
- 5.4** What would the temperature do if the reactor ran adiabatically? (4)

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**END****[Total: 92 Marks]**

**USEFUL EQUATIONS AND FORMULAE**

$$PV = nRT; \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}; \quad v = \frac{V^t}{m}; \quad \dot{m} = uA\rho; \quad \dot{n} = \frac{uA}{vM}; \rho = v^{-1}; \quad \dot{V} = \frac{V}{t}$$

$$t(^{\circ}\text{C}) = T(\text{K}) - 273.15; \quad t(^{\circ}\text{F}) = T(\text{R}) - 459.67; \quad t(^{\circ}\text{F}) = 1.8t(^{\circ}\text{C}) + 32;$$

$$P_g = \frac{F}{A} = \frac{mg}{A} = \frac{\rho V g}{A} = \frac{Ah\rho g}{A}; \quad P_{abs} = P_g (\text{or } \rho gh) + P_{atm}$$

$$\text{Interpolation: } M = \left( \frac{X_2 - X}{X_2 - X_1} \right) M_1 + \left( \frac{X - X_1}{X_2 - X_1} \right) M_2 \quad \text{OR} \quad M = \frac{M_1(X_2 - X) + M_2(X - X_1)}{X_2 - X_1}$$

Double Interpolation:

	$X_1$	$X$	$X_2$
$Y_1$	$M_{1,1}$		$M_{1,2}$
$Y$		$M = ?$	
$Y_2$	$M_{2,1}$		$M_{2,2}$

$$M = \left[ \left( \frac{X_2 - X}{X_2 - X_1} \right) M_{1,1} + \left( \frac{X - X_1}{X_2 - X_1} \right) M_{1,2} \right] \frac{Y_2 - Y}{Y_2 - Y_1} + \left[ \left( \frac{X_2 - X}{X_2 - X_1} \right) M_{2,1} + \left( \frac{X - X_1}{X_2 - X_1} \right) M_{2,2} \right] \frac{Y - Y_1}{Y_2 - Y_1}$$

$$\Delta E_{univ} = \Delta E_{syst} + \Delta E_{surr} = 0; \quad \eta = \frac{W_{irreversible}}{W_{reversible}}; \quad \frac{dm_{cv}}{dt} = \Delta m = \dot{m}_{out} - \dot{m}_{in}$$

$$\text{Energy balance for open systems: } \frac{d(mU)_{cv}}{dt} = -\dot{m}\Delta \left[ U + \frac{1}{2}u^2 + gh \right] + \dot{Q} + \dot{W}$$

$$\text{Energy balance for steady-state flow processes: } \Delta \dot{m} \left( H + \frac{1}{2}u^2 + gh \right) = \dot{Q} + \dot{W}_s$$

$$\text{Single Phase: } \ln \frac{V_2}{V_1} = \beta(T_2 - T_1) - \kappa(P_2 - P_1)$$

Mechanically reversible closed system processes:

$$\text{Constant } V: \quad Q = n\Delta U = n \int_{T_1}^{T_2} C_v dT = nC_v \Delta T$$

$$\text{Constant } P: \quad Q = n\Delta H = n \int_{T_1}^{T_2} C_p dT = nC_p \Delta T; \quad W = -R(T_2 - T_1)$$

$$\text{Constant } T: \quad Q = -W = RT_1 \ln \frac{V_2}{V_1} = -RT_1 \ln \frac{P_2}{P_1} = P_1 V_1 \ln \frac{V_2}{V_1} = -P_1 V_1 \ln \frac{P_2}{P_1}$$

$$\text{Adiabatic: } \frac{T_2}{T_1} = \left( \frac{V_1}{V_2} \right)^{R/C_v}; \quad \frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{R/C_p}; \quad \frac{P_2}{P_1} = \left( \frac{V_1}{V_2} \right)^{C_p/C_v}; \quad \gamma = \frac{C_p}{C_v};$$

$$\text{Adiabatic: } W = \Delta U = C_v \Delta T = \frac{R\Delta T}{\gamma - 1} = \frac{R(T_2 - T_1)}{\gamma - 1} = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} = \frac{P_1 V_1}{\gamma - 1} \left[ \left( \frac{P_2}{P_1} \right)^{\gamma - 1/\gamma} - 1 \right] = \frac{RT_1}{\gamma - 1} \left[ \left( \frac{P_2}{P_1} \right)^{\gamma - 1/\gamma} - 1 \right]$$

$$\text{Virial equation truncated to 2 terms: } Z = \frac{PV}{RT} = 1 + \frac{BP}{RT}; \quad \text{truncated to 3 terms: } Z = 1 + \frac{B(T)}{V} + \frac{C(T)}{V^2};$$

$$\text{Lee/ Kesler correlation: } Z = Z^o + \omega Z^1;$$

$$\text{Generalized Pitzer correlation: } Z = 1 + (B^0 + \omega B^1) \frac{P_r}{T_r}; \quad B^0 = 0.083 - \frac{0.422}{T_r^{1.6}}; \quad B^1 = 0.139 - \frac{0.172}{T_r^{4.2}}$$

$$\text{IG: } Q = n\Delta H = n \int_{T_0}^{T_1} \frac{C_p^{ig}}{R} dT = n \left[ AT_o(\tau - 1) + \frac{B}{2} T_o^2(\tau^2 - 1) + \frac{C}{3} T_o^3(\tau^3 - 1) + \frac{D}{T_o} \left( \frac{\tau-1}{\tau} \right) \right] = n \frac{\langle C_p \rangle_H}{R} (T_1 - T_0); \text{where, } \tau = \frac{T}{T_0}$$

$$\langle C_p \rangle_H = R \left[ A + \frac{B}{2} T_o(\tau + 1) + \frac{C}{3} T_o^2(\tau^2 + \tau + 1) + \frac{D}{\tau T_o^2} \right]$$

Clapeyron equation:  $\Delta H = T\Delta V \frac{dP^{sat}}{dT}$

General entropy change:  $\Delta S = C_p \ln \frac{T_2}{T_1} - \ln \frac{P_2}{P_1}$

Entropy change for IG:  $\frac{\Delta S}{R} = \frac{\langle C_p \rangle_s}{R} \ln \frac{T}{T_o} - \ln \frac{P}{P_o}; \frac{\langle C_p \rangle_s}{R} = A + \left[ BT_o + \left( CT_o^2 + \frac{D}{\tau^2 T_o^2} \right) \left( \frac{\tau+1}{\tau} \right) \right] \left( \frac{\tau-1}{\ln \tau} \right)$

For residual properties:  $V^R = V - V^{ig}; \quad H^R = H - H^{ig}; \quad G^R = RT \ln \phi$

$$S^R = S - \left( S^{ig} + \frac{R}{Mr} \ln \frac{P_2}{P_1} \right); \quad \frac{H^R}{RT_c} = \left( \frac{H^R}{RT_c} \right)^0 + \omega \left( \frac{H^R}{RT_c} \right)^1; \quad \frac{S^R}{R} = \left( \frac{S^R}{R} \right)^0 + \omega \left( \frac{S^R}{R} \right)^1$$

$$\frac{H^R}{RT_c} = P_r \left[ \left( 0.083 - \frac{1.097}{T_r^{1.6}} \right) + \omega \left( 0.139 - \frac{0.894}{T_r^{4.2}} \right) \right]; \quad \frac{S^R}{R} = -P_r \left[ \frac{0.675}{T_r^{2.6}} + \omega \left( \frac{0.722}{T_r^{5.2}} \right) \right];$$

$$Z = 1 + \beta - q\beta \frac{(Z - \beta)}{(Z + \epsilon \beta)(Z + \sigma \beta)}$$

Fugacity and fugacity coefficient:  $\phi = (\phi^0)(\phi^1)^\omega; f = \phi P; \ln \phi = \sum_i X_i \ln \phi_i; \ln \phi = \frac{P_r}{T_r} (B^0 + \omega B^1)$

Raoult's law:  $y_i P = x_i P_i^{sat}$  where  $P = \sum_i x_i P_i^{sat}$  or  $P = \frac{1}{\sum_i y_i / P_i^{sat}}$

Modified Raoult's law:  $y_i P = x_i \gamma_i P_i^{sat}$  where  $P = \sum_i x_i \gamma_i P_i^{sat}$  or  $P = \frac{1}{\sum_i y_i / \gamma_i P_i^{sat}}$

Table A.1: Conversion Factors	
Quantity	Conversion
Length	1 m = 100 cm = 3.28084(ft) = 39.3701(in)
Mass	1 kg = 10 <sup>3</sup> g = 2.20462(lb <sub>m</sub> )
Force	1 N = 1 kg m s <sup>-2</sup> = 10 <sup>5</sup> (dyne) = 0.224809(lb <sub>f</sub> )
Pressure	1 bar = 10 <sup>5</sup> kg m <sup>-1</sup> s <sup>-2</sup> = 10 <sup>5</sup> N m <sup>-2</sup> = 10 <sup>5</sup> Pa = 10 <sup>2</sup> kPa = 10 <sup>6</sup> (dyne) cm <sup>-2</sup> = 0.986923(atm) = 14.5038(psia) = 750.061(torr)
Volume	1 m <sup>3</sup> = 10 <sup>6</sup> cm <sup>3</sup> = 10 <sup>3</sup> liters = 35.3147(ft) <sup>3</sup> = 264.172(gal)
Density	1 g cm <sup>-3</sup> = 10 <sup>3</sup> kg m <sup>-3</sup> = 62.4278(lb <sub>m</sub> )(ft) <sup>-3</sup>

Energy	1 J = 1 kg m <sup>2</sup> s <sup>-2</sup> = 1 N m = 1 m <sup>3</sup> Pa = 10 <sup>-5</sup> m <sup>3</sup> bar = 10 cm <sup>3</sup> bar = 9.86923 cm <sup>3</sup> (atm) = 10 <sup>7</sup> (dyne) cm = 10 <sup>7</sup> (erg) = 0.239006(cal) = 5.12197 × 10 <sup>-3</sup> (ft) <sup>3</sup> (psia) = 0.737562(ft)(lb <sub>f</sub> ) = 9.47831 × 10 <sup>-4</sup> (Btu) = 2.77778 × 10 <sup>-7</sup> kWhr
Power	1 kW = 10 <sup>3</sup> W = 10 <sup>3</sup> kg m <sup>2</sup> s <sup>-3</sup> = 10 <sup>3</sup> J s <sup>-1</sup> = 239.006(cal) s <sup>-1</sup> = 737.562(ft)(lb <sub>f</sub> ) s <sup>-1</sup> = 0.947831(Btu) s <sup>-1</sup> = 1.34102(hp)

Table A.2: Values of the Universal Gas Constant	
$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1} = 8.314 \text{ m}^3 \text{ Pa mol}^{-1} \text{ K}^{-1}$ $= 83.14 \text{ cm}^3 \text{ bar mol}^{-1} \text{ K}^{-1} = 8.314 \text{ cm}^3 \text{ kPa mol}^{-1} \text{ K}^{-1}$ $= 82.06 \text{ cm}^3 (\text{atm}) \text{ mol}^{-1} \text{ K}^{-1} = 62,356 \text{ cm}^3 (\text{torr}) \text{ mol}^{-1} \text{ K}^{-1}$ $= 1.987 (\text{cal}) \text{ mol}^{-1} \text{ K}^{-1} = 1.986 (\text{Btu}) (\text{lb mole})^{-1} (\text{R})^{-1}$ $= 0.7302 (\text{ft})^3 (\text{atm}) (\text{lb mole})^{-1} (\text{R})^{-1} = 10.73 (\text{ft})^3 (\text{psia}) (\text{lb mole})^{-1} (\text{R})^{-1}$ $= 1,545 (\text{ft}) (\text{lb}_f) (\text{lb mole})^{-1} (\text{R})^{-1}$	