Ex/CHE/PC/B/T/216/2023(S)

BACHELOR OF ENGINEERING CHEMICAL ENGINEERING EXAMINATION, 2023

(2nd Year, 1st Semester, Supplementary)

CHEMICAL PROCESS PRINCIPLES

Time: 3 Hours Ful Marks: 100

(50 Marks for each Part)

Use separate Answer Scripts for each Part

Part -1 (For 50 Marks)

(Attempt all questions)

		Marks
	CO1	
Q1	Do solve the conversions i). PSI to Pa ii). atm to Pa iii). PSF to Pa iv). Pressure of 1 mm H2O to Pa v). Poundal to N	5
	CO3	
Q2	Suppose you pour a gallon of water on a yowling cat 10 ft below your bedroom window. a) How much potential energy (ft.lb_f) does the water lose? b) How fast is the water traveling (ft/s) just before impact? c) True or false: Energy must be conserved, therefore the kinetic energy of the water before impact must equal the kinetic energy of the cat after impact.	10
	CO4	
Q3	An adiabatic membrane separation unit is used to dry (remove water vapor from) a gas mixture containing 10.0 mole% H_2O (v), 10.0 mole% CO, and the balance CO2. The gas enters the unit at 30 °C and flows past a semipermeable membrane. Water vapor permeates through the membrane into an air stream. The dried gas leaves the separator at 30 °C containing 2.0 mole% H_2O (v) and the balance CO and CO_2. Air enters the separator at 50 °C with an absolute humidity of 0.002 kg H_2O /kg dry air and leaves at 48 °C. Negligible quantities of CO, CO_2, O2, and N2 permeate through the membrane. All gas streams are at approximately 1 atm. a) Draw and label a flowchart of the process and carry out a degree-of-freedom analysis to verify that you can determine all unknown quantities on the chart. b) Calculate (i) the ratio of entering air to entering gas (kg humid air/mol gas) and (ii) the relative humidity of the exiting air. c) List several desirable properties of the membrane. (Think about more than just what it allows and does not allow to permeate).	15
	CO5	
Q4	The dehydrogenation of ethanol to form acetaldehyde $$C_2H_5OH(v) \rightarrow CH_3CHO\ (v) + H_2(g)$$ is carried out in a continuous adiabatic reactor. Ethanol vapor is fed to the reactor at 400 °C, and a conversion of 30% is obtained. Calculate the product temperature.	15
Q5	(i) What do you mean by adiabatic flame temperature and ignition log? (ii) What is a flame? Why some are flames blue and some yellow?	5

[Turn over

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B.E. CHEMICAL ENGINEERING SECOND YEAR FIRST SEMESTER SUPPLEMENTARY EXAM 2023

Chemical Process Principles

Full Marks: 100 **PART-II (50 Marks)** **Time: 3h**

Use Separate Answer scripts for each part

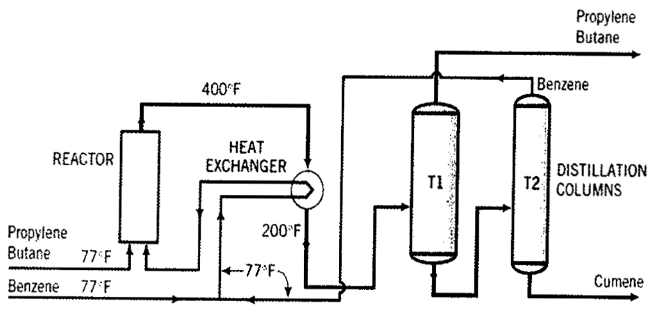
All symbols have usual significance, if not stated otherwise

Assume any missing data

Answer questions from all COs with following marks distribution

CO No.	CO1	CO2	CO3	CO4	CO5
Marks	5	10	5	20	10

<table>
<tr><td>CO1</td><td></td></tr>
<tr><td>1. a) 1.a) Identify the unit operations and processes in the following flowsheet. Categorize (batch etc.) all the systems involved.


</td><td>5</td></tr>
<tr><td>CO2</td><td></td></tr>
<tr><td>2. The pressure drop ΔP in a pipe of diameter D and length l due to turbulent flow depends on the velocity V, viscosity μ, density ρ and roughness ε. Using Buckingham's Π-theorem, obtain an expression for ΔP.</td><td>10</td></tr>
<tr><td>CO3</td><td></td></tr>
<tr><td>3. A liquid mixture containing 30.0 mole% benzene (B), 25.0% toluene (T), and the balance xylene (X) is fed to a distillation column. The bottoms product contains 98.0 mole% X and no B, and 96.0% of the X in the feed is recovered in this stream. The overhead product is fed to a second column. The overhead product from the second column contains 97.0% of the B in the feed to this column. The composition of this stream is 94.0 mole% B and the balance T.
(i) Draw and label a flowchart of this process and do the degree-of-freedom analysis to prove that for an assumed basis of calculation, molar flow rates and compositions of all process streams can be calculated from the given information. Write in order the equations you would solve to calculate unknown process variables. In each equation (or pair of simultaneous equations), circle the variable(s) for which you would solve. Do not do the calculations.</td><td>5</td></tr>
<tr><td>CO4</td><td></td></tr>
<tr><td>4. Chlorobenzene (C_6H_5Cl), an important solvent and intermediate in the production of many other chemicals, is produced by bubbling chlorine gas through liquid benzene in the presence of ferric</td><td>12</td></tr>
</table>

chloride catalyst. In an undesired side reaction, the product is further chlorinated to dichlorobenzene, and in a third reaction the dichlorobenzene is chlorinated to trichlorobenzene. The feed to a chlorination reactor consists of essentially pure benzene and a technical grade of chlorine gas (98 wt% Cl_2, the balance gaseous impurities with an average molecular weight of 25.0). The liquid output from the reactor contains 65.0 wt% C_6H_6 , 32.0 wt% C_6H_5Cl, 2.5 wt% $C_6H_4Cl_2$, and 0.5 wt% C_6H_3Cl). The gaseous output contains only HCl and the impurities that entered with the chlorine.

(a) You wish to determine (i) the percentage by which benzene is fed in excess, (ii) the fractional conversion of benzene, (iii) the fractional yield of monochlorobenzene, and (iv) the mass ratio of the gas feed to the liquid feed. Without doing any calculations, prove that you have enough information about the process to determine these quantities.

(b) Perform the calculations.

(c) Why would benzene be fed in excess and the fractional conversion kept low?

(d) What might be done with the gaseous effluent?

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5. Methane is burned with 25% excess air in a continuous adiabatic reactor. The methane enters the reactor at 25°C and 1.10 atm at a rate of 5.50 L/s, and the entering air is at 150°C and 1.1 atm. Combustion in the reactor is complete, and the reactor effluent gas emerges at 1.05 atm. Calculate (a) the temperature and (b) the degrees of superheat of the reactor effluent. (Consider water to be the only condensable species in the effluent.)

CO5

Answer any one between 6 or 7

6. A liquid-phase chemical reaction with stoichiometry A → B takes place in a semibatch reactor. The rate of consumption of A per unit volume of the reactor contents is given by the first-order rate expression 10

$$r_A[\text{mol/(L.s)}] = kC_A$$

where C_A (mol A/L) is the reactant concentration. The tank is initially empty. Beginning at a time t = 0, a solution containing A at a concentration C_{A0}(mol A/L) is fed to the tank at a steady rate v(L/s).

(a) Write a differential balance on the total mass of the reactor contents. Assuming that the density of the contents always equals that of the feed stream, convert the balance into an equation for dV/ dt, where V is the total volume of the contents, and provide an initial condition. Then write a differential mole balance on the reactant, A, letting $N_A(t)$ equal the total moles of A in the vessel, and provide an initial condition. Your equations should contain only the variables N_A, V, and t and the constants v and C_{AO}.

(b) Without attempting to integrate the equations, derive a formula for the steady-state value of N_A.

(c) Integrate the two equations to derive expressions for V(t) and $N_A(t)$, and then derive an expression for $C_A(t)$.

or

7. A steam radiator is used to heat a 60-m^3 room. Saturated steam at 3.0 bar condenses in the radiator: and emerges as a liquid at the saturation temperature. Heat is lost from the room to the outside at a rate

$$Q(\text{kJ/h}) = 30.0(T - T_o)$$

where T (°C) is the room temperature and To = 0°C is the outside temperature. At the moment the radiator is turned on, the temperature in the room is 10°C.

(a) Let m_s(kg/h) denote the rate at which steam condenses in the radiator and n(kmol) the quantity of air in the room. Write a differential energy balance on the room air, assuming that n remains constant at its initial value, and evaluate all numerical coefficients. Take the heat capacity of air (C_v) to be constant at 20.8 J/(mol·°C).

(b) Write the steady-state energy balance on the room air and use it to calculate the steam condensation rate required to maintain a constant room temperature of 24°C.

(c) Integrate the transient balance to calculate the time required to achieve a temperature of 23°C, assuming that the steam rate is that calculated in part (b).