B.E. CHEMICAL ENGINEERING SECOND YEAR SECOND SEMESTER EXAMINATION 2019

CHEMICAL PROCESS CALCULATIONS

Use separate answer scripts for each part.

Time: Three hours | *Full marks: 100*
(50 marks for each part)

Part-I

There are two modules in this part. You need to answer ***two compulsory questions from module 1, any one*** *question from* ***module 2.***

Write all the assumptions.

MODULE 1: *Answer* **the compulsory questions**

1. An evaporation-crystallization process (Fig.1) is used to obtain solid potassium sulfate from an aqueous solution of this salt. The fresh feed to the process contains 19.6 wt% K_2SO_4. The wet filter cake consists of solid K_2SO_4 crystals and a 40.0 wt% K_2SO_4 solution, in a ratio 10 kg crystals/kg solution. The filtrate, also a 40.0% solution, is recycled to join the fresh feed. Of the water fed to the evaporator, 45.0% is evaporated. The evaporator has a maximum capacity of 175 kg water evaporated/s.

   (a) Do degrees of freedom analysis for the overall system.
   (a) Calculate the production rate of solid K_2SO_4 , the rate at which fresh feed must be supplied to achieve this production rate and the ratio kg recycle/kg fresh feed when the evaporator is operating at the maximum capacity.

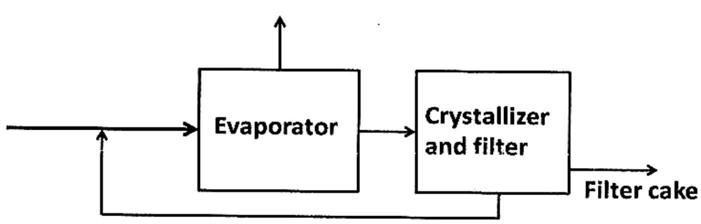

Fig. 1

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2. An aqueous solution containing 0.02 mol/L of species A is fed into a holding tank that initially contains 50 liters of pure water. The reactant decomposes at a rate

$$r[\text{mol A/L.s}] = 0.0425C_A ,$$

where C_A, mol/L, is the concentration of A in the tank. The volumetric feed rate of the solution, $\dot{v}(t)$, increases linearly over a 20-second period from 0 to 40 L/s and stays constant at that rate

[Turn over

thereafter until the tank is filled to the desired level. The density of the feed stream is constant.

(i) Write a differential balance for the total mass of the tank contents and the mass of species A in the tank. and provide initial conditions.

(ii) Sketch the shapes of the plots you would expect for the volume of the tank contents, V (L), and the concentration of A in the tank C_A (mol/L) versus time without solving the equations.

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***MODULE 2:** Answer __any one__ question*

3. Sulfur dioxide is oxidized to sulfur trioxide in a small pilot-plant reactor:

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g),$$

The standard heat of reaction for the above reaction is $\Delta\hat{H}_r^{\circ} = -195\ \text{kJ/mol}$. SO_2 and 100% excess air are fed to the reactor at 450° C. The reaction proceeds to a 65% SO_2 conversion, and the products emerge from the reactor at 550° C. The production rate of SO_3 is 2 kmol/min. Calculate the heating requirement for this process in kW. You may use the following data.

Heat capacity, C_p , kJ/mol°C, T is in °C	
$SO_2(g)$	$38.9 \times 10^{-3} + 3.9 \times 10^{-5}T - 3.1 \times 10^{-8}\,T^2 + 8.6 \times 10^{-12}\,T^3$
$SO_3(g)$	$48.05 \times 10^{-3} + 9.19 \times 10^{-5}T - 8.54 \times 10^{-8}\,T^2 + 32.40 \times 10^{-12}\,T^3$
$O_2(g)$	$29.1 \times 10^{-3} + 1.16 \times 10^{-5}T - 0.608 \times 10^{-8}\,T^2 + 1.3 \times 10^{-12}\,T^3$

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4. An air conditioner cools 226 m^3 /min of humid air at 36° C and 98% relative humidity to 10° C. Calculate the rate of condensation of water in the unit and the cooling duty (rate of heat transfer) using the psychrometric chart attached.

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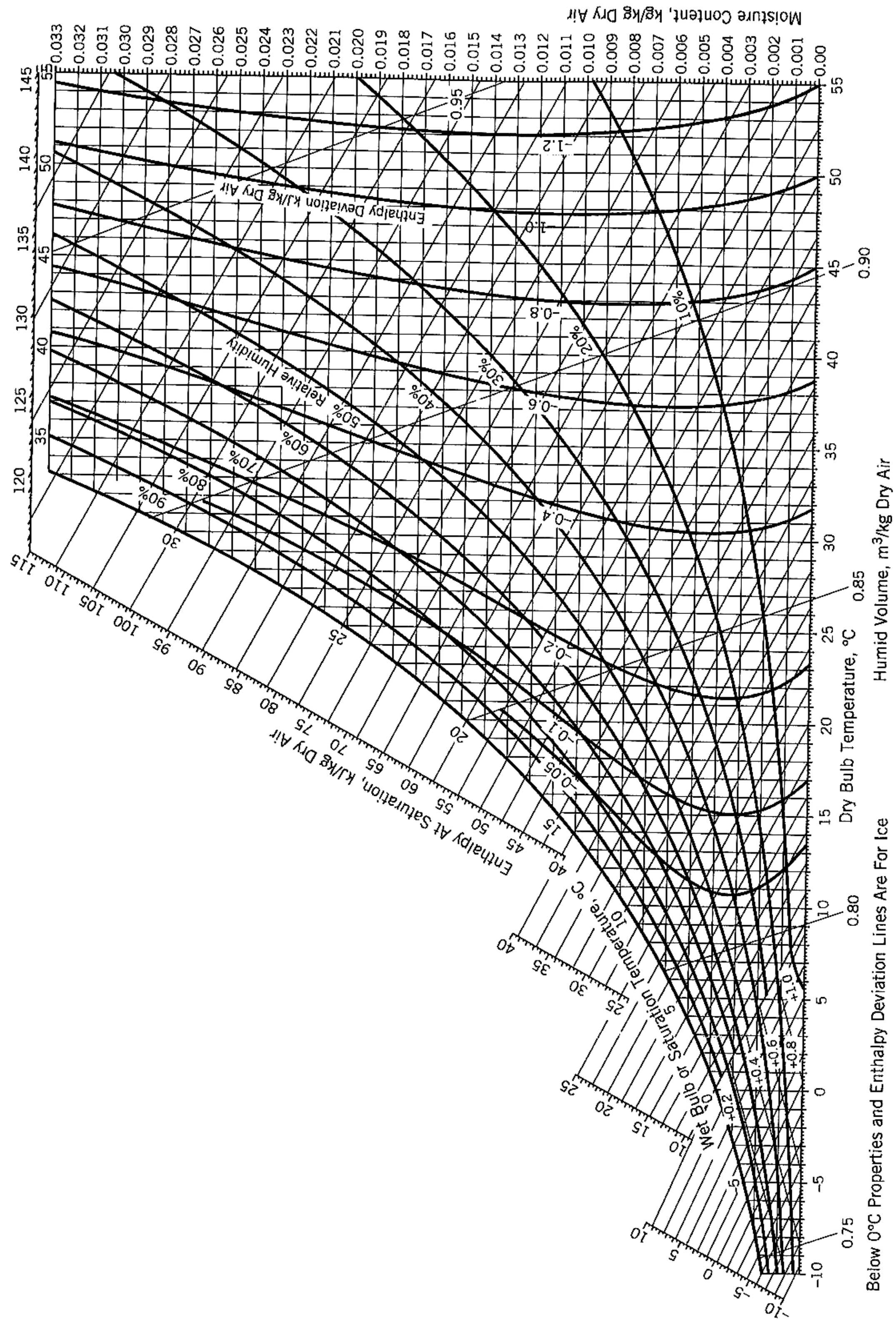

Figure 8.4-1 Psychrometric chart—SI units. Reference states: H_2O (L, 0°C, 1 atm), dry air (0°C, 1 atm). (Reprinted with permission of Carrier Corporation.)

PART – II

Assume any missing data

All the symbols have usual meaning

Answer Question No. 1 and any TWO from the rest

1. A mixture of benzene and toluene at 25°C is fed to a continuous single-stage evaporator at a rate of 1250 mol/s. The mixture contains 62 % benzene and the rest toluene. The liquid and vapor streams leaving the evaporator are both at 95°C. The liquid stream from the evaporator contains 10.5 mole% benzene and the vapor stream is essentially pure benzene. Calculate the heating requirement for this process. **[20]**

Thermodynamic Data: (All temperatures are in degree Celsius)

Benzene: $C_{p,\text{ liq.}} = \left[0.1265 + 23.4\times10^{-5}\times T\right]$ kJ/mol·°C

$C_{p,\text{ vap.}} = \left[0.074 + 32.95\times10^{-5}\times T - 25.2\times10^{-8}\times T^2\right]$ kJ/mol·°C

$\Delta\hat{H}_v\left(80.1^oC\right) = 30.77$ kJ/mol

Toluene: $C_{p,\text{ liq.}} = \left[0.149 + 32.4\times10^{-5}\times T\right]$ kJ/mol·°C

$C_{p,\text{ vap.}} = \left[0.0942 + 38.0\times10^{-5}\times T - 27.86\times10^{-8}\times T^2\right]$ kJ/mol·°C

$\Delta\hat{H}_v\left(110.6^oC\right) = 33.47$ kJ/mol

2. In ammonia production plant, ammonia is produced in the reaction of nitrogen and hydrogen. The fresh feed to the process contains nitrogen, hydrogen and 0.2 mole% inert gas. The feed is combined with a recycle stream and the combined stream is fed to a reactor. The reactor effluent passes to a condenser that removes all of the ammonia formed. All the inert gas and unreacted nitrogen and hydrogen leave the condenser and recycled to the reactor. To avoid buildup of the inert in the system, a purge stream is withdrawn from the recycle. The feed to the reactor contains 24.0 mole% nitrogen, 73.0 mole% hydrogen and 3.0 mole% inert gas. The single-pass conversion of nitrogen is 20.0%. Draw and label a complete flowchart of the process. Taking a basis of 100 mol/h combined feed to the reactor, determine molar flow rates and molar composition of all the process streams. **[15]**

3. a) A fuel gas containing 95 mole% methane and the rest ethane is burned completely with 25% excess air. The stack gas leaves the furnace at 900°C and is cooled to 450°C. If 100 moles of the fuel gas fed to the furnace, calculate the amount of heat (kJ) that must be transferred during the cooling. **[10]**

Thermodynamic Data

Compound	$\hat{H}$ at 450°C (kJ/mol)	$\hat{H}$ at 900°C (kJ/mol)
CO_2	18.85	42.94
H_2O	15.12	33.32
O_2	13.38	28.89
N_2	12.70	27.19

b) 1284 moles of ethanol at 70°C and 3054 moles of water 20°C are to be mixed in a well insulated flask. The energy balance for this constant pressure process is $Q = \Delta H$. Neglecting evaporation and the heat of mixing, estimate the final mixture temperature. **[5]**

Thermodynamic Data: (All temperatures are in degree Celsius)

- $C_{p,\text{Ethanol}} = \left[0.1031 + 0.557\times10^{-3}\times T\right]$ kJ/mol.°C
- $C_{p,\text{H}_2\text{O}} = 75.4\times10^{-3}$ kJ/mol.°C

4. A storage tank contains 10,000 kg of a solution containing 5 wt% acetic acid. A fresh feed of 500 kg/min water is entering the tank and dilutes the solution in the tank. The mixture is stirred well and the product leaves the tank continuously at a rate of 500 kg/min. At what instant of time the acid concentration in the tank will drop to 1 wt% acetic acid? After one hour of operation, what will be the concentration in the tank? **[15]**