B.E. CHEMICAL ENGINEERING SECOND YEAR SECOND SEMESTER EXAMINATION 2018

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 three modules in this part. You need to answer ***any one*** *question from* ***module 1****,* ***any one*** *question from* ***module 2*** *and* ***two compulsory questions*** *from* ***module 3.***

Write all the assumptions.

MODULE 1: *Answer* ***any one*** *question*

1. Methanol is produced by reacting carbon monoxide and hydrogen: $CO + 2H_2 \rightarrow CH_3OH$. A fresh feed stream containing CO and H_2 joins a recycle stream and the combined stream is fed to a reactor (Fig.1). The reactor outlet stream flows at a rate of 350 mol/min and contains 63.25 mol% H_2 , 27.28 mol% CO, and 9.47 mol% CH_3OH. This stream enters a cooler in which most of the methanol is condensed. The liquid methanol condensate is withdrawn as a product, and the gas stream leaving the condenser, which contains CO, H_2, and 0.40 mole% uncondensed CH_3OH vapour, is the recycle stream that combines with the fresh feed.

   (a) Do degrees of freedom analysis to prove that you have enough information to determine the molar flow rates of CO and H_2 in the fresh feed.
   (b) Calculate
   (i) the molar flow rates of CO and H_2 in the fresh feed,
   (ii) the production rate of liquid methanol, and
   (iii) the single-pass conversion of carbon monoxide.

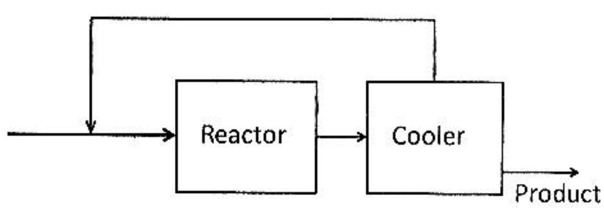

Fig. 1

4+12

2. Fresh orange juice contains 12.0 wt% solids and the balance water, and concentrated orange juice contains 42.0 wt% solids. An evaporator is used for the concentration. A fraction of the fresh juice bypasses the evaporator (Fig. 2). The juice that enters the evaporator is concentrated to 58 wt% solids, and the evaporator product stream is mixed with the bypassed fresh juice to achieve the desired final concentration of 42.0 wt% solids.
   (a) Perform the degree-of freedom analysis for the overall system.

(b) Calculate the amount of product (42% concentrate) produced per 100 kg fresh juice fed to the process and the fraction of the feed that bypasses the evaporator.

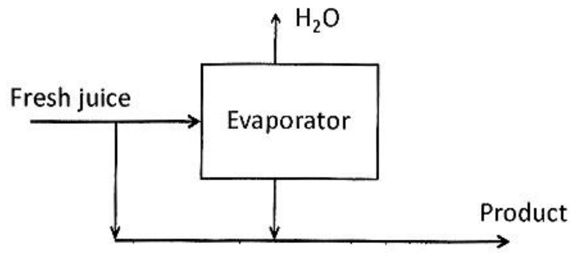

Fig. 2

4+12

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

3. A liquid stream containing 50.0 mole % benzene and the balance toluene at 25° C is fed to a continuous single-stage evaporator at a rate of 1320 mol/s. The liquid and vapor streams leaving the evaporator are both at 95° C. The liquid contains 42.5 mole % benzene and the vapor contains 73.5 mole % benzene. Calculate the heating requirement for this process in kW. You may use the following data.

	Benzene	Toluene
Boiling point at 1 atm (T_b)	80.10°C	110.62°C
$\Delta\widehat{H}_v$ at T_b ,kJ/mol	30.765	33.47

Heat capacity, C_p , kJ/mol°C, T is in °C	
Benzene (l)	$126.5 \times 10^{-3} + 23.4 \times 10^{-5}T$
Benzene (g)	$74.06 \times 10^{-3} + 32.95 \times 10^{-5}T - 25.20 \times 10^{-8}\,T^2 + 77.57 \times 10^{-12}\,T^3$
Toluene(l)	$148.8 \times 10^{-3} + 32.4 \times 10^{-5}T$
Toluene(g)	$94.18 \times 10^{-3} + 38.00 \times 10^{-5}T - 27.86\,X10^{-8}T^2 + 80.33\, \times 10^{-12}\,T^3$

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4. The synthesis of methanol from carbon monoxide and hydrogen is carried out in a continuous vapour phase reactor at 5.00 atm absolute. The feed contains CO and H_2 in stoichiometric proportion and enters the reactor at 25°C and 5.00 atm at a rate of 3495 mol /h. The product stream emerges from the reactor at 127°C. The rate of heat transfer from the reactor is 17.05 kW. Calculate the fractional conversion achieved and the molar flow rate of the product stream.

$$CO + 2H_2 \rightarrow CH_3OH$$

Data:

Standard heat of formation , $\Delta\widehat{H}_f^{\circ}$, kJ/mol	
CO(g)	-110.52
CH_3OH(g)	-201.2

Heat capacity, C_p , kJ/mol°C, T is in °C	
CO(g)	$0.02895 + 0.411 \times 10^{-5}T + 0.3548 \times 10^{-8}T^2 - 2.22 \times 10^{-12}T^3$
$CH_3OH(g)$	$0.04293 + 8.301 \times 10^{-5}T - 1.87 \times 10^{-8}T^2 - 8.03 \times 10^{-12}T^3$
$H_2(g)$	$0.02884 + 0.00765 \times 10^{-5}T + 0.3288 \times 10^{-8}T^2 - 0.8698 \times 10^{-12}T^3$

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***MODULE 3:** Answer **both** the questions*

5. Air at 35°C and 70% relative humidity is cooled to 10°C at a constant pressure of 1 atm. Use the Psychrometric chart to find
   (i) the fraction of the water that condenses
   (ii) change in enthalpy of humid air as it is brought from the initial to the final condition per kg of dry air.
   (iii) wet bulb temperature of humid air at the initial condition.

4+2+2

6. A liquid-phase reaction with stoichiometry $A \rightarrow B$ takes place in a continuous stirred-tank reactor. The rate of consumption of A equals $0.005C_A$[mol/(s.L of reaction volume)], where C_A, mol/L, is the concentration of A in the reactor. Feed enters the reactor at a rate of 2 L/s; the concentration of the reactant in the feed is 15 mol A/L). The product leaves the reactor at a rate of 2 L/s. The volume of the reactor contents is 12 L. The reactor may be considered perfectly mixed, so that the contents are uniform and the concentration of A in the product stream equals that inside the reactor. The reactor is initially filled with a solution that contains 5mol A/L, and the inlet and outlet flows then begin.

   (i) Write a differential balance on species A in the reactor and provide an initial condition.
   (ii) Obtain C_A as a function of time.

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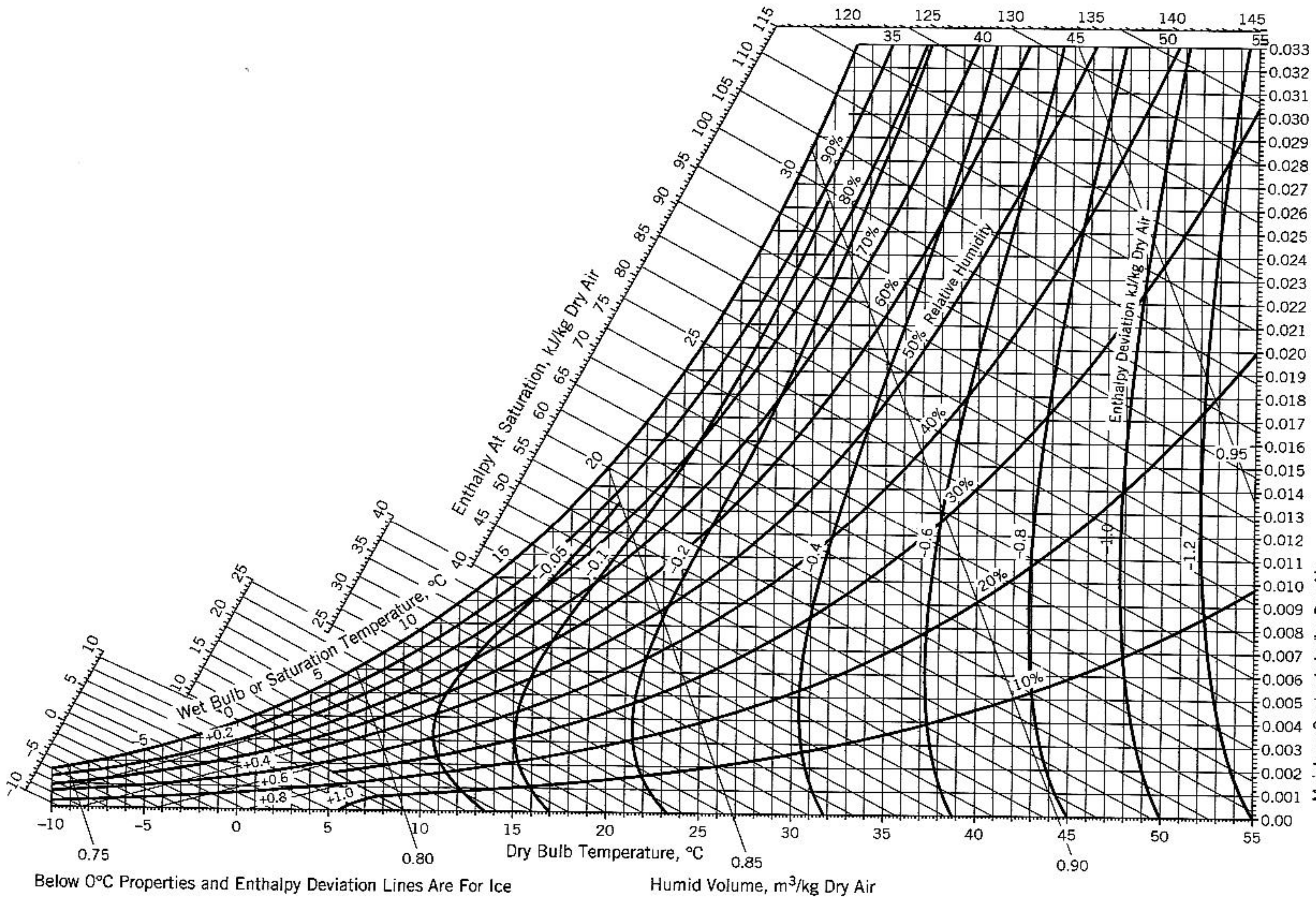


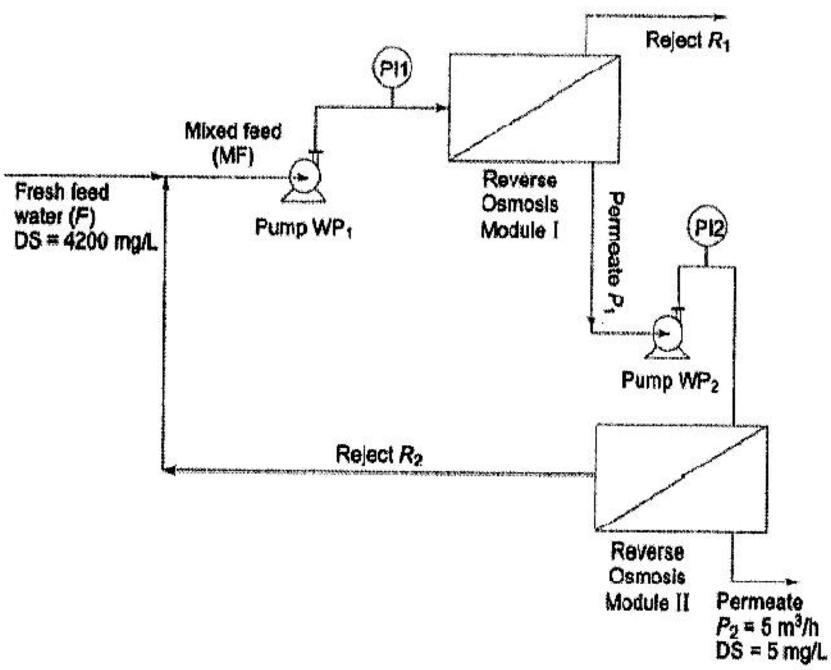
Figure 8.4-1 Psychrometric chart—SI units. Reference states: H_2O (L, 0°C, 1 atm), dry air (0°C, 1 atm). (Reprinted with permission of Carrier Corporation.)

PART II

Group A

(Question 1 is compulsory. Assume any missing data)

1. Production of treated water is required at the rate of 5m3/h with 5mg/L dissolved solids (DS) in a plant. Raw water with 4200mg/L DS is available for treatment purpose. A two stage reverse osmosis set up shown below is used for the treatment. Module I is designed for 66% recovery of the feed to the module while Module II is designed for 80% recovery. Rejection of 98.5% solids is achieved in the second Module. While reject stream R_1 from the first module is discarded as effluents, reject stream R_2 will be recycled and mixed with the incoming raw water F. Based on RO membrane characteristics, both feed pumps are designed to feed the modules at 12bar.



(i) Perform degrees of freedom analysis

(ii) Calculate F, R_1, P, R_2, recycle ratio R_2/F

(iii) Also determine the rejection of solids from Module I.

(iv) What are the advantages of recycling and purging operations?

3 + 5 + 6 + (3+3) = 20

Group B

(Answer any one)

2. (a) 1kg/s air at 350K and 10% humidity is mixed with 5kg/s air at 300K and 30% humidity? Use the psychometric chart to determine the enthalpy, humidity and temperature of the mixed stream of air and explain the steps?

4 + 3 + 3 = 10

(b) Air containing 0.005kg of water vapour per kg dry air is heated to 325K in a dryer and passed to a set of shelves. It leaves the shelves at 60% humidity and is again reheated to 325K and passed over another set of shelves, again leaving at 60% humidity. This is again repeated for third and fourth shelves after which the air leaves the dryer. On the assumption that the material on each shelf has reached the wet bulb temperature and that the heat losses from the dryer is neglected determine using the psychometric chart

(i) The temperature on each shelf

(ii) The temperature to which the inlet air has to be raised to carry out the drying in a single step

4 + 6 = 10

3. A natural gas containing 18 mole % ethane and balance methane is burned with 20% excess air in a boiler furnace. The fuel gas enters at 298K and the air is pre heated to 423K. The heat capacities of the stack gas components are given below. The standard heats of combustion of methane and ethane are -890.36kJ/mol and -1599.9kJ/mol respectively. The latent heat of vaporization of water at 298K is 44kJ/mol.

Component	**C_p (J/ mol. K)**
CO_2	50
H_2O (v)	38.5
O_2	33.1
N_2	31.3

(a) Assuming complete combustion of the fuel, calculate adiabatic flame temperature

(b) Calculate the flame temperature if the percentage of ethane is increased to 30%

(c) How would the flame temperature change if the percentage excess air were increased? Explain your answer.

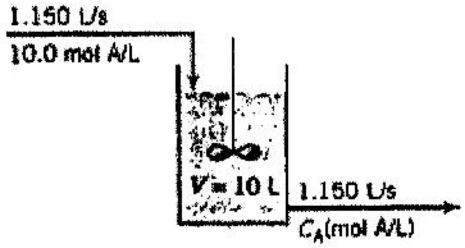
9 + 9 + 2 = 20

Group C

(Answer any one)

4. A tank holds $100m^3$ of water is which 4kg of salt is dissolved. Water with concentration $0.01kg/m^3$ enters the tank at a flow rate of $5m^3/min$ and the salt solution overflows at $4m^3/min$. If the mixing in the tank is such that the salt concentration is uniform, find the amount of salt left in the tank after 30min. What will be the nature of the plot of salt concentration with time? Find the time required to bring down the salt concentration in the tank to $0.02kg/m^3$? Write clearly all the necessary equations. 10

5. A liquid-phase reaction with stoichiometry A→ B takes place in a continuous well-mixed 10.0-liter stirred-tank reactor. A schematic diagram of the process is shown below. The reactor may be considered perfectly mixed, so that the contents are uniform and the concentration of A in the product stream equals that inside the tank. The tank is initially filled with a solution that contains 2.00mol A/L, and the inlet and outlet flows then begin.



A ⟶ B, rate = $0.0050C_A$(mol A react/(L·s))

(i) Calculate C_{AS}, the steady-state concentration of A in the tank (the value approached as *t* approaches infinity)

(ii) Sketch the shape expected for a plot of C_A versus *t* and dC/dt versus t.

(iii) What will be the value of C_A at t = 100 s and t = 300 s 10

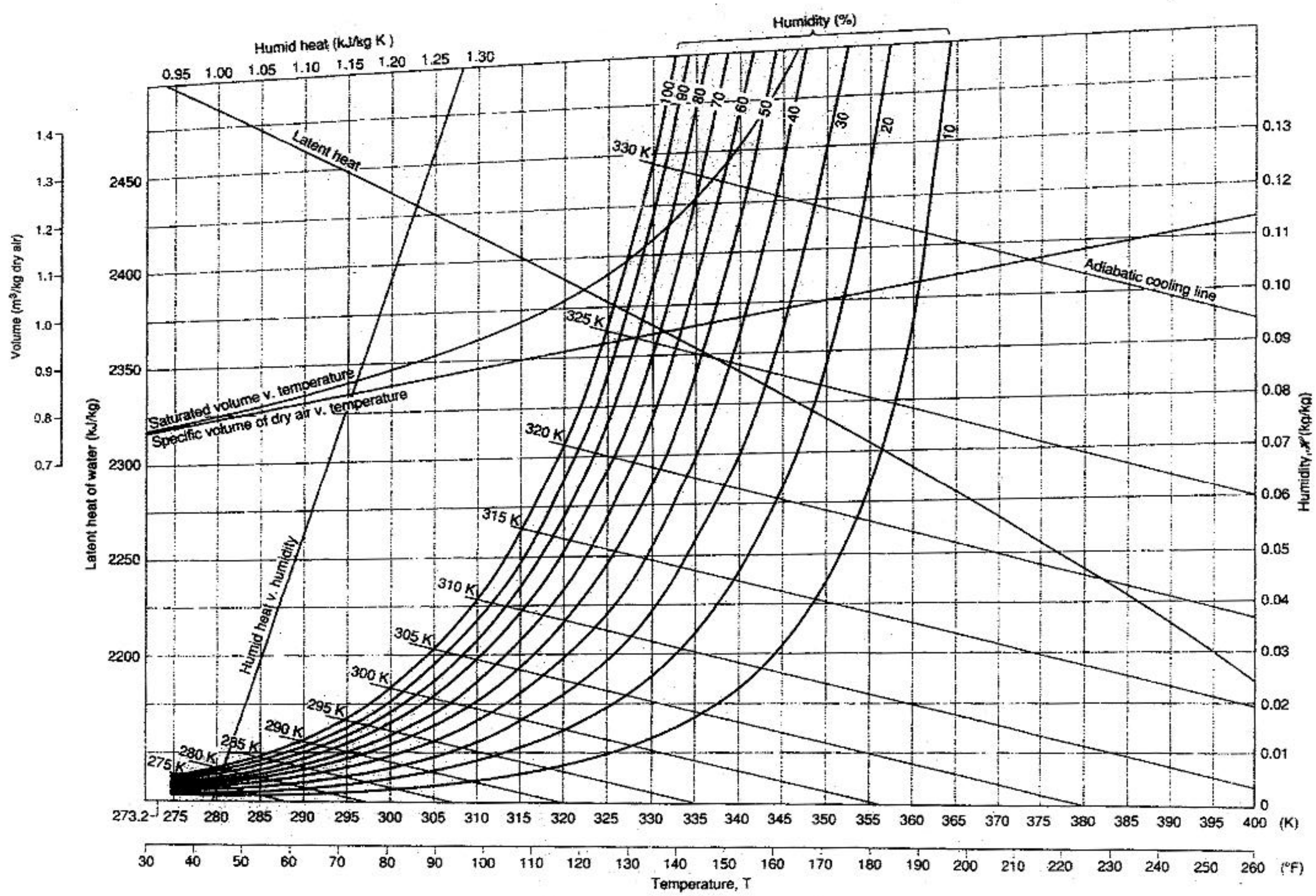


Figure 13.4. Humidity–temperature chart (See also the Appendix)