B.E. CHEMICAL ENGINEERING THIRD YEAR FIRST SEMESTER EXAM 2024

3rd Year, 1st Semester

SEPARATION PROCESSES - I

(50 Marks for each Part)

Use separate answer script for each Part

Time: 3 Hours | Full Marks: 100

Part I (50 Marks)

Answer Q1 OR Q2 and any One (1)from the rest

1. *Humidification* **[3+2+9+16=30]**

a) Why do we call a natural draft cooling tower a 'Hyperbolic Tower'? Why the design is based on a hyperbolic shape?

b) Classify the cooling towers based on air draft.

c) Derive an expression for the height of the packing section of a cooling tower in terms of the number of gas enthalpy transfer units and the height of gas enthalpy transfer units. Extrapolate it to the following form of the Merkel's equation. $k_y'\bar{a}$ is the individual volumetric gas phase mass transfer coefficient; L is the liquid flow rate; z is the packing height within the cooling tower; C_{WL} is the specific heat capacity of the liquid; T_{Li} and T_{Lo} are the inlet and outlet temperatures of the cooling water respectively; H_i' is the enthalpy at saturation of the air-water system at any temperature where tie-line meets the equilibrium curve; H' is the enthalpy of the unsaturated air-water system at any temperature where tie-line meets the operating line.

$$\int_{T_{Li}}^{T_{Lo}} \frac{dT_L}{H_i' - H'} = \frac{k_y'\bar{a}}{LC_{WL}} z$$

d) A cooling tower is to be designed to cool water from 32°C to 22°C by countercurrent contact with air of a dry-bulb temperature of 22°C and an RH of 40%. The water rate is 5400 kg/m^{2}h and the air rate is 1.3 times the minimum. Determine the tower height if $k_y'\bar{a}$ is 5750 kg/m^{3}h ($\Delta Y'$), where $\Delta Y'$ is the departure between saturation humidity and absolute humidity of the unsaturated air-water system at any temperature where tie-line meets the operating line. The volumetric water-side heat transfer coefficient is given by $h_L\bar{a} = 0.059L^{0.51}G_S$ Kcal/m^{3}hK, where L and G_S are mass flow rates of water and air (dry basis) respectively. Use only psychrometric chart, attached herewith, for all necessary values. Please do not use any correlation.

2. *Absorption* **[5+7+18=30]**

a) Enumerate the steps to arrive at the minimum liquid flow rate $(L/G)_{min}$, graphically, for absorption in a packed tower with the help of a schematic diagram of an absorption column including a differential control element of height dz.

[Turn over

b) Determine the tower packing height required in a packed absorption tower using the height of a transfer unit method, employing the height of an individual gas phase transfer unit (H_{tG}) and the number of individual gas phase transfer units (N_{tG}).

c) A gas stream containing 92 mol% N_2 and 8% CO_2 is passed through a packed absorber, in which pure and cool water at 5°C is used as a solvent. The operation is assumed to be isothermal at 5°C and isobaric at 10 atm. The liquid flow rate is 1.5 times the minimum liquid flow rate $(L/G)_{min}$. Determine the tower packing height using the height of a transfer unit method, as derived in part a) required to absorb 90 mol% of CO_2. *Consider the log mean concentration gradient and changes in the gas flux between the top and bottom sections*. The feed gas rate is 1200 kg/h. The tower's cross-sectional area is 1 m^2. The volumetric gas and liquid phase mass transfer coefficients are, $k_y'a$ =0.082 kmol/m^3. s. mole fraction and $k_x'a =$ 1.22 kmol/m^3. s. mole fraction, respectively. *Data*: Henry's constant of CO_2 in water at 5°C is 876 atm/mole fraction.

3. *Drying* **[3+8+9=20]**

a) With respect to the movement of moisture within a solid, briefly discuss liquid diffusion, capillary movement, and vapor diffusion in the light of specific driving forces.

b) Derive two expressions for total drying time under constant drying conditions considering the constant drying rate period and first falling rate period. Express the first falling rate as i) a linear function of the moisture content and ii) a quadratic function of the form $N=\beta X^2$, where β is a constant.

c) A wet solid having 40% moisture (dry basis) is to be dried on a tray dryer till a final moisture content of 2% is reached. The solid loading is 28 kg dry solid per m^2 tray area. Two critical moisture values are there: X_{c1} =0.179 and X_{c2}=0.095. A laboratory test gives a drying rate of 6 kg/m^2 h in the constant rate period. In the first falling rate period, the drying flux is linear with respect to the moisture content; In the second falling rate period, the drying flux varies as the square of the moisture content. The equilibrium moisture is negligible. Calculate the total drying time in h if the drying conditions are the same as maintained during the laboratory tests. Clearly mention any assumption made.

4. *Humidification; Drying* **[4+3+4+9=20]**

a) Calculate the approach of a cooling tower having an effectiveness of 75% and a cooling water temperature difference of 7°C.

b) What is the purpose of a blowdown in a cooling tower circuit? An induced draft cooling tower is having a cooling water circulation flow of 7200 m^3/h. Calculate the quantity of make-up water required in a day. Assume evaporation, blowdown, and drift losses to be 0.9%, 0.2% and 0.003% respectively.

c) Perform the Material and Enthalpy balance of the following continuous dryer. Here: S_s=Flow rate of solid (kg/h, dry basis); G_s = Flow rate of air (kg/h, dry basis); Q=rate of heat lost (kJ/h); Use: $H_G' = 1.005\,(T_G - T_0) + 1.88\,Y((T_G - T_0) + 2500\,Y$, where T_G and T_0 are the gas and reference temperatures respectively, H_G' = enthalpy of the gas and Y is the humidity of the gas.

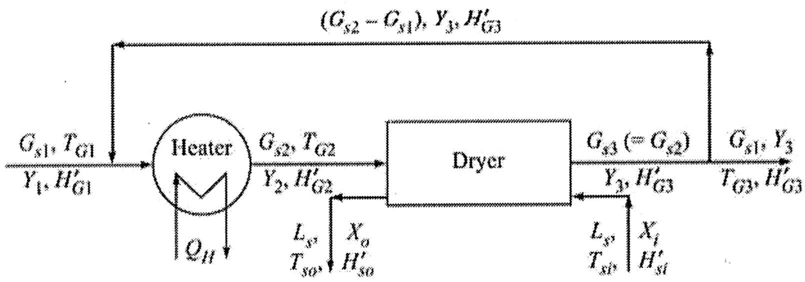
$C_{pl} \rightarrow$ Specific heat of liquid (water) = 4.187 kJ/ kg K;

$C_{pG} \rightarrow$ pecific heat of dry gas (air) = 1.005 kJ/ kg K;

$C_{pv} \rightarrow$ Specific heat of vapor (water vapor) = 1.88 kJ/ kg K;

$\lambda_S \rightarrow$ Heat of vaporization of water at reference temperature (0°C) =2500 kJ/kg

d) A non-hygroscopic filter cake is to be dried in a continuous countercurrent dryer from 27% moisture to 1% moisture (wet basis) at a rate of 900 kg per hour. The material enters the dryer at 27°C and leaves at 52°C. Fresh air is mixed with a part of the moist air leaving the dryer and heated to a temperature of 120°C in a finned air heater using low-pressure steam (4 kg/cm^2, gauge). Calculate (a) the flow rate of fresh air, (b) the fraction of the air leaving the dryer that is recycled, (c) the theoretical steam requirement, and (d) the heat loss from the dryer, if any. Given: temperature of fresh air: 26°C; RH (%):10; humidity of the air leaving the heater: 0.03 kg/kg dry air; humidity and temperature of the air leaving the dryer: 0.05 kg/kg dry air, 70°C; specific heat of the dry solid: 900 J/kg.K.



Schematic of a dryer with recirculation of air.

5. *Absorption; Drying* **[3+2+3+2+10=20]**

a) Highlight the criteria for selection of a solvent for absorption on the basis of *solubility*. Give two different types of examples.

b) Why do we choose a low viscose solvent for absorption?

c) An absorption column cannot operate, even theoretically, at a liquid rate less than the minimum. Explain with the help of a sketch.

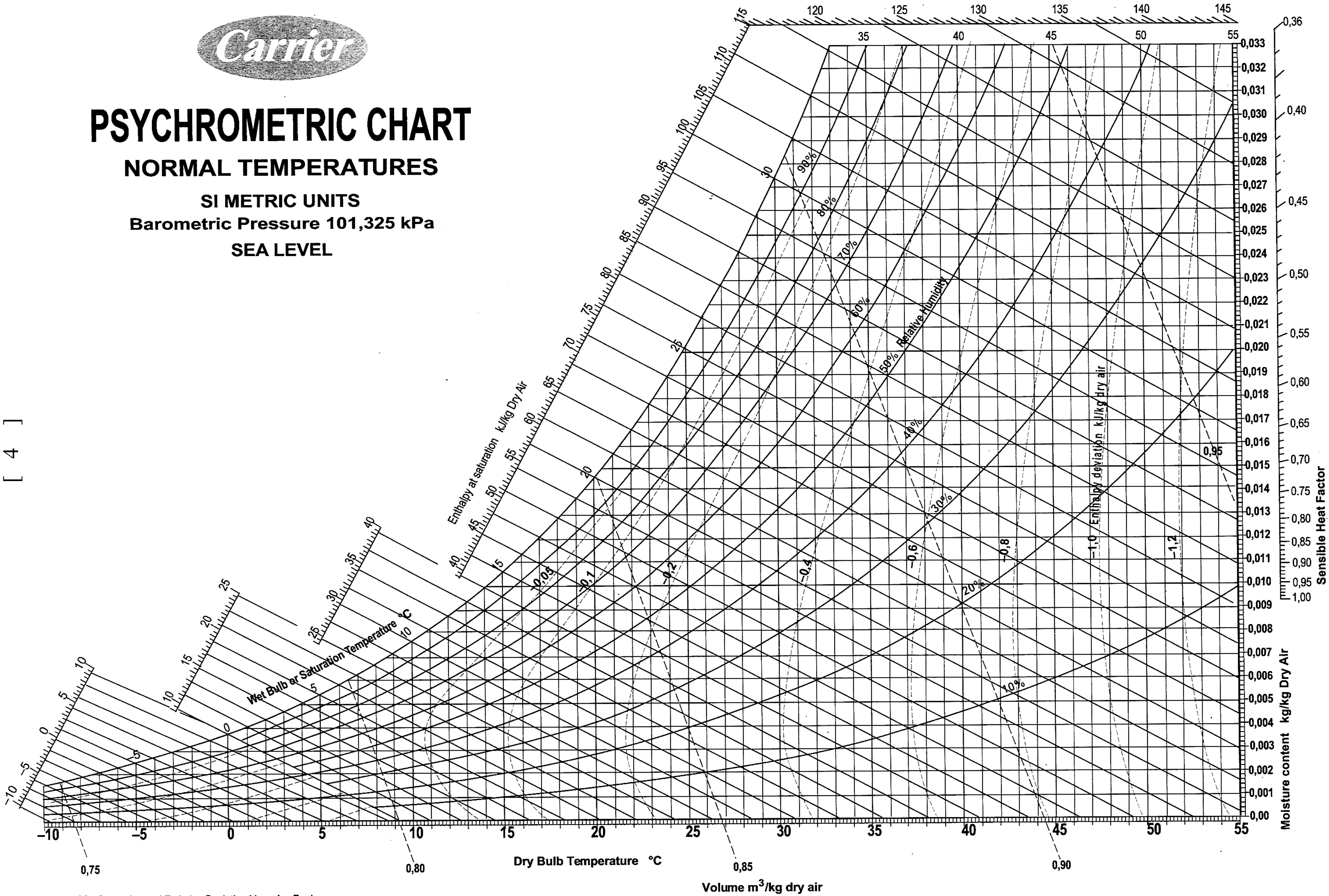
d) If the equilibrium relation, expressed in terms of mole ratio unit, is linear [$Y=\alpha X$], the minimum liquid rate can be determined algebraically. Explain in short.

e) Starting with a differential heat balance over a thin strip of the solid layer on a cross-circulation tray dryer, derive expressions for i) length of the tray in terms of length of the gas phase heat transfer units and number of gas phase transfer units, and ii) rate of heat transfer to the solid and iii) total drying time when drying rate, temperature and the humidity of the gas change along the length of the tray.

PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS
Barometric Pressure 101,325 kPa
SEA LEVEL



Below 0°C, Properties and Enthalpy Deviation Lines Are For Ice

Ex/Che/PC/B/T/311/2024

BACHELOR OF CHEMICAL ENGINEERING EXAMINATION, 2024

(3rd Year, 1st Semester)

SEPARATION PROCESSES I

Time : Three hours | Full Marks : 100

(50 Marks for each Part)

Assume any missing data

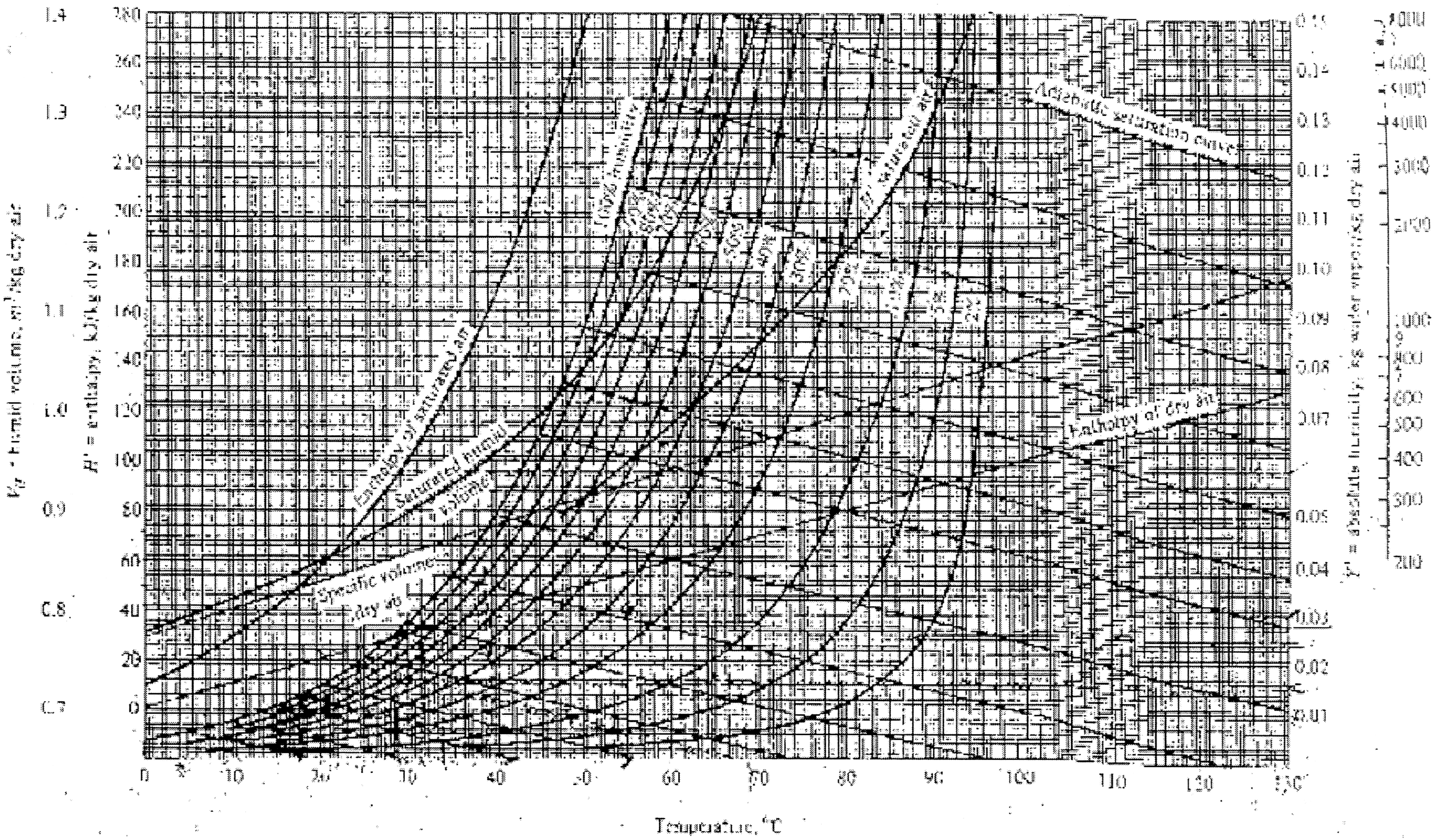
Answer 10 marks from Q.No. 1, 35 marks from Q. No. 2 and 5 marks from q.No. 3

PART: II (50 Marks)

Q.No.	CO	Question	Marks
1.	1 & 3	a) Show that for air-water system, wet-bulb temperature and adiabatic saturation temperature are equal.	3
		b) In gas absorption process, operating line lies **below** the equilibrium curve. Is it a correct statement? Explain.	2
		c) What is "loading region" in a counter-current packed bed gas-liquid contactor?	3
		d) Component A of a binary mixture is diffusing from point 1 to 2. The total pressure is doubled by keeping all other parameters including mole fraction of A at point 1 and 2 constant. How will the rate of diffusion change? Explain.	2
		e) Why long and hyperbolic shaped towers are preferred as natural draft cooling tower?	2
		f) Select a type of contactor and justify if gas phase needs to be dispersed in continuous liquid medium.	3
			3
2.	2	a) 1000 $m^3/hr\text{-}m^2$ of an air-ammonia mixture at standard conditions, containing 6% NH_3 by volume is to be scrubbed with water in a counter-current packed tower to remove 98% NH_3. The temperature will be kept constant at 20°C and the pressure at 1 atm. The equilibrium relation is given by $y^* = 0.746x$, where x,y are mole	20

		fractions of ammonia in water and air, respectively. The overall mass transfer coefficient has been estimated to be 70 kmol/hr.m^3atm. Calculate the minimum flow rate of water required for the operation. Also, find out the number of transfer units and height of the packed bed assuming the operation to be carried out with water flow rate 1.6 times the minimum.	
		b) A plant requires 15 kg/sec of cooling water to flow through its condenser. The water will leave the condenser at 45°C. it is proposed to cool the water for reuse by contact with air in induced draft cooling tower. Entering air is at 30°C (dry bulb temperature) and 24°C (wet bulb temperature). Water is to be cooled to within 5°C of inlet air wet bulb temperature; an air to water ratio of 1.5 times the minimum is used. Make-up water will come from a well at 10°C, hardness 500 ppm dissolved solid. The circulating water is not to contain more than 2000 ppm hardness. The overall volumetric mass transfer coefficient is 0.9 kg/m^3-s-Δy for a liquid rate at least 2.7 kg/m^2-s and gas rate 2 kg/m^2-s i) Compute the dimension of the packed section of the column ii) Compute the amount of make-up water required considering drift/windage loss as 0.3% of circulating water.	25
		c) 2000 m3/hr at 70°C, a atmosphere, humidity 0.22 is brought into contact with water at adiabatic saturation temperature and air is adiabatically humidified to 70% saturation. Estimate: i) Water temperature ii) Absolute humidity and temperature of leaving air iii) Volumetric flow rate of air leaving the humidifier iv) Volume of adiabatic humidifier if volumetric gas phase mass transfer coefficient is 4690 kg/hr-m3ΔH	10

		d) i) The total drying time needed for a batch of solid is 13.14 hrs. The weight of the wet solid is 160 kg and initial and final moisture content of the solid are 25 and 6% respectively. The drying surface is 1 m2/40 kg of dry weight. The critical moisture content of the solid is 0.2 kg moisture/kg dry solid. The rate of drying at the constant rate period is given as 0.003 kg water/m2-s. Find the slope of the falling rate region assuming b zero in N = mX+b. ii) Show that if internal diffusion of moisture controls for long time, rate of drying is proportional to moisture content and inversely proportional to thickness of solid bed; independent of gas velocity and its humidity.	8+7
3.	4	a) How will the rate of drying during constant rate drying period be affected if the humidity of drying air is increased?	3
		b) Which type of contactor (between tray column and packed column) is more suitable to handle flammable and toxic liquids and why?	3
		c) What is 'permeability' of gas?	2
		d) What do you mean by cascades?	2



(a)

Psychrometric chart for air-water vapor, 1 std atm abs, in SI units.