BACHELOR OF CHEMICAL ENGINEERING EXAMINATION, 2018

(3rd Year, 1st Semester)

SEPARATION PROCESS I

Time : Three hours | Full Marks : 100

(50 marks for each Part)

Use separate answer script for each part.

PART I

Answer any *two*
Assume any missing data

1.a) Name at least two equipments used in each following cases of gas-liquid mass transfer operations with reasons:

i) Gas phase dispersed in gas-liquid system

ii) Liquid phase dispersed in gas-liquid system

b) Why long and hyperbolic shaped towers are preferred as natural draft cooling tower?

c) In an experimental study of absorption of ammonia by water in a wetted wall column, the overall gas phase mass transfer coefficient, K_G was estimated at 2.72×10^{-4} kmol/m^2.s.atm. At one point of the column the gas contained 10 mol% ammonia and the liquid phase concentration was 6.42×10^{-2} kmol ammonia/m^3 of solution when temperature is 293 K and the total pressure is 1 atm. 85% of the resistance to mass transfer lies in gas phase. If Henry's law constant is 9.35×10^{-3} atm.m^3/kmol, calculate the individual film coefficients and interfacial composition.

d) What do you mean by cascades? Describe cross flow cascades with three ideal stages.

e) In tray tower operation, Murphree efficiency and point efficiency are equal in some limiting cases. When?

6+4+8+4+3

2.a) A gas mixture containing 0.20 mole fraction of CO_2 is to be scrubbed to reduce its CO_2 mole fraction to 0.002, using 15.3 wt % aqueous mono ethanolamine (MEA) solution at 25°C and 1000 mm Hg pressure. The components other than CO_2 in the gas mixture may be treated as inert. The MEA solution enters the tower counter-current mode and contains 0.46 mol of CO_2 per mol of MEA in the solution. If the MEA used is 1.2 times the minimum, find the minimum MEA flow rate to get desired separation and number of theoretical stages required for the separation. Assume the solution to be concentrated.

P_{CO_2} (mm Hg)	2	7.5	10	20	30	40	50	60	70
CO_2 (mol per mol of MEA solution)	0.475	0.50	0.51	0.53	0.55	0.565	0.575	0.58	0.582

b) Batches of 100Kg cotton yarn (dry weight) are dried in atmospheric air pressure (1 bar) from X = 0.53 to X = 0.11 Kg water/Kg dry material. The drying air is at constant temperature 62^{0}C and constant humidity 0.0134 kg vapour / kg dry air. The drying rate is constant at 15 kg/hr until water content is $X = 0.23$ and equilibrium is obtained with $X^* = 0.05$ kg/kg dry yarn. With water content between $X = 0.23$ and X^*, the drying rate is assumed to be proportional to the free moisture content in the yarn.

a) Determine the temperature of the yarn in the constant rate period.
b) Determine the drying time for each batch
c) Assuming the drying rate in both the constant rate and in the falling rate period to be proportional to the dry air velocity to the 0.8 power, calculate the percentage increase in air flow rate needed to reduce drying time to 75% of the total calculated under (b).

15+10

3.a) What are the major drawbacks of 'Penetration Theory' to describe mass transfer at phase boundary?

b) What is the significance of the terms "Range" and "Approach" applicable for cooling tower operation?

c) What are the differences between critical moisture content and equilibrium moisture content of a solid?

d) A cooling tower receives warm water at 43^0C at a mass flow rate of 7000 Kg/m^2.h. A cooling range of 13^0C is to be achieved by counter-current contact with air. The air enters at a rate of 4200 Kg/m^2.h at a dry bulb temperature of 31^0C and humidity of 0.01516 Kg/Kg dry air. The overall volumetric mass transfer coefficient is 2500 Kg/m^3.h.ΔH. Determine the number of overall gas phase transfer units and the height of packing of the required bed.

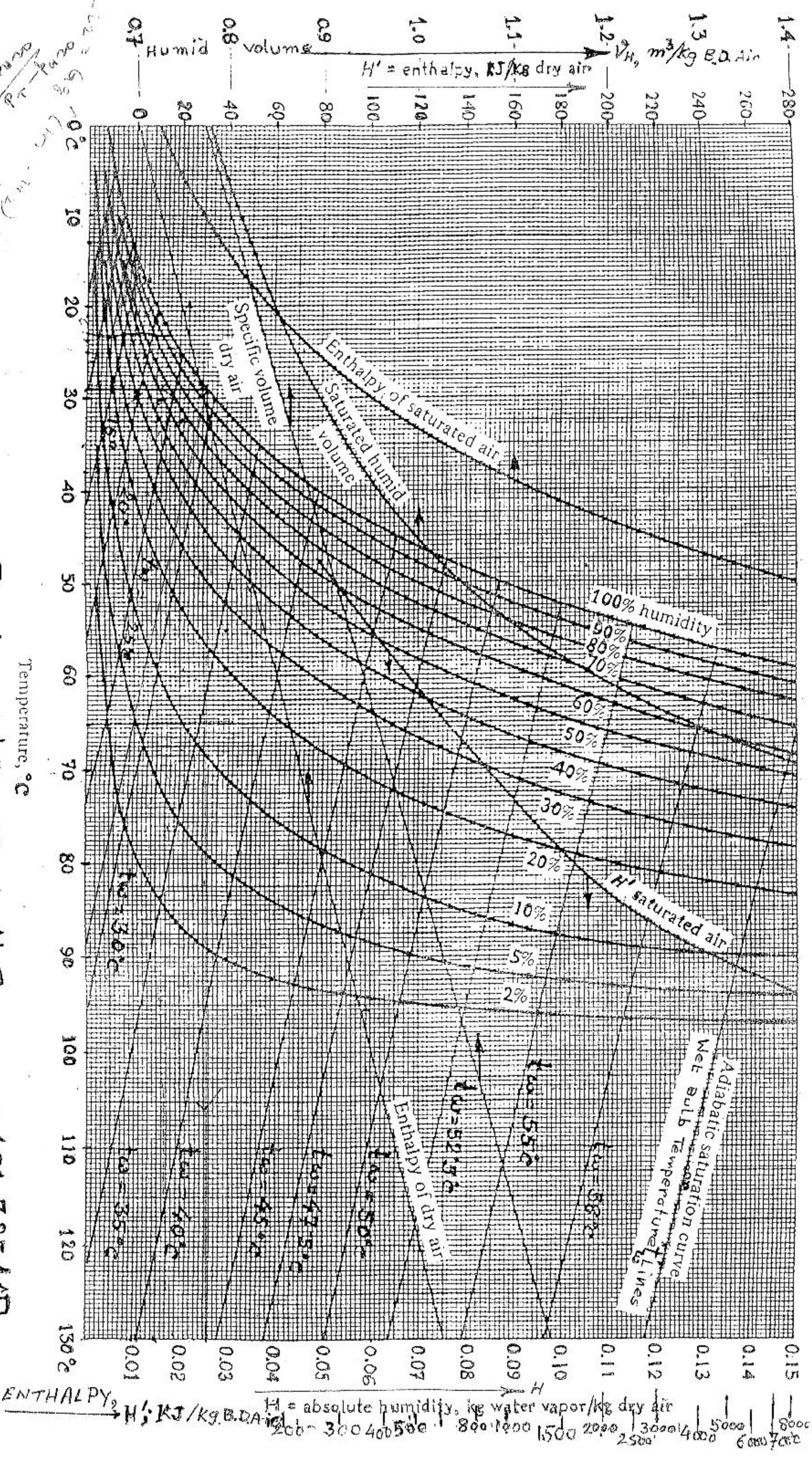
OR

Ammonia is to be absorbed from air at atmospheric pressure by means counter-current packed tower, using a dilute solution of H_2SO_4 as absorbent. In this system, gas film prevents the controlling resistance. The inlet gas rate of 800 lb/hr(ft)^2 and acid rate of 1000 lb/hr(ft)^2 will be used. Under this condition, k_{Ga} = 18 lbmoles/hr.(ft)^3.atm.Determine the tower height needed for absorption of

a) 50% of ammonia from inlet gas containing 1% ammonia by volume in air
b) 99% of ammonia from inlet gas containing 1% ammonia by volume in air.

The equilibrium relationship is $Y = X$.

3+4+3+15



Psychrometric Chart. Ab Pressure: 101.325 kPa

Separation Process I

Use separate answerscript for Part I and part II

Part II

Answer any two questions

The symbols have their usual meaning

Assume any missing data

1. Sulphur dioxide was being absorbed by water in an apparatus. The bulk gas and liquid concentration of SO_2 at one point in the equipment is 10 mol% and 0.4% SO_2 respectively. The liquid density is 990 kg/m^3. The temperature was 50 °C and the total pressure 1 std atm. Equilibrium data at 50 °C are:

kg SO_2/100 kg water	0.2	0.3	0.5	0.7
Partial pressure SO_2, mm Hg	29	46	83	119

(a) The overall mass transfer coefficient based on gas concentration was estimated to be K_G = 7.36x10^{-10} kmol/m^2.s. (N/m^2). Of the total diffusional resistance, 47% is in the gas phase and the remaining in the liquid phase. [17]

(i) Determine the interfacial composition in both the phases?

(ii) Calculate the value of individual mass transfer coefficient's k_G , k_y and k_x .

(iii) Calculate the overall coefficient based on liquid phase concentration, K_x

(b) Determine the interfacial composition in both the phases of the above problem if the value of F_G = 1.8x10^{-4} kmol/m^2.s and F_L = 3.2x10^{-4} kmol/m^2.s is specified. [8]

2. (a) The average heat transfer coefficient for a fluid flowing at right angle to a circular cylinder is given by $Nu = 0.15 + 0.6\,\mathrm{Re}^{0.5}\,\mathrm{Pr}^{0.25}$
where, Nu and Re are calculated based on cylinder diameter and bulk fluid properties.

Estimate the rate of sublimation of a cylinder of naphthalene, 6 mm diameter exposed to air stream flowing at a velocity of 5 m/s. The vapor pressure of naphthalene at the surface temperature may be taken as 10 mm Hg. The diffusivity in air may be taken as 6.25x10^{-6} m^2/s. The corresponding physical properties of the gas at the mean temperature and composition are estimated to be: density = 4.1 kg/m^3; viscosity = 2.7x10^{-5} kg/m.s. The bulk air is at 1 std atm pressure and 40 °C. [12]

(b) Air at 310 K and atmospheric pressure flows through a smooth pipe 0.025 m ID at a velocity of 10 m/s. The tube is 6 m long. Pressure taps at the ends of the 6m section indicate that the pressure drop is 7x10^3 N/m^2. Estimate the mass transfer coefficient, F? [7]

(c) Nickel carbonyl in gaseous form is produced by passing carbon monoxide gas through a bed of nickel spheres. The reaction is

$$Ni + 4CO \rightarrow Ni(CO)_4$$

Estimate the mass transfer flux of CO where the bulk phase mole fraction of CO in the bed is 0.01 and the value of *F* type mass transfer coefficient is 5.5×10^{-3} kmol/m^2.s. The reaction may be assumed to be rapid and the partial pressure of CO at the metal surface is essentially zero. [6]

3. (a) Benzene is evaporated into a air stream. It flows through a duct 0.5 m by 0.5 m cross section. The pressure and temperature at one point in the duct are 900 mm Hg, 45°C and at this point the average velocity is 5.0 m/s. A wet bulb thermometer (wick wetted by benzene) indicates that the temperature at this point is 35°C. Calculate the benzene carried by the duct (kg/s) from the following data. [12]

The density and viscosity of air is 1.06 kg/m^3 and 1.95×10^{-5} kg/m.s. The diffusivity (in air), heat capacity of benzene and latent heat of vaporization may be taken to be 1.05×10^{-5} m^2/s, 1256 J/kg.K and 33 KJ/mol respectively. The vapor pressure of benzene is given by

$$\log_{10} P(\text{bar}) = 4.7258 - \frac{1660.65}{T(K) - 1.461}$$

(b) Water saturated with air at 20 °C is passed through hydrophobic fibers at 50 cm/s. The fibers are 1 m long with an inner diameter of 500 μm. Vacuum is applied on the outside to remove air as fast as it diffuses to the fiber wall. Estimate the mass transfer coefficient of oxygen if the air saturation of water reduces to half at the outlet of the fibers? The solubility of air in water is 0.02 v/v of which O_2 is 35.6%. [6]

(c) Derive the expression to determine the depth of packing, *Z* for packed bed absorption tower

$$Z = \int_{y_2}^{y_1} \frac{G\,dy}{F_G a(1-y)\ln\left[\dfrac{1-y_i}{1-y}\right]}$$

State the procedure with relevant equation for estimating Z from the above expression if the equilibrium curve and operating line is provided. [7]