KATHMANDU UNIVERSITY
End Semester Examination
May/June, 2022

Marks Scored:

Level : B.E.
Year : III
Course : CHEG 313
Semester : II
Exam Roll No. :
Time: 30 mins.
F. M. : 10
Registration No.:
Date :

SECTION "A"
[20 Q. × 0.5 = 10 marks]

Encircle the most appropriate option.

1. Operating velocity in a packed tower is usually _____ the flooding velocity.
   a. equal to b. half c. one third d. twice

2. The dimensionless group in mass transfer that is equivalent to Prandtl number in heat transfer is
   a. Nusselt number b. Sherwood number c. Schimdt number d. Stanton number

3. According to the surface renewal theory, the unit of fractional rate of surface renewal is
   a. m^2sec^2 b. m^2sec^{-1} c. $m.sec^{-1}$ d. sec^{-1}

4. According to the penetration theory of mass transfer, the mass transfer coefficient (k) varies with diffusion coefficient (D) of the diffusing species as
   a. D b. $D^{-1/2}$ c. $D^{1/2}$ d. $D^{3/2}$

5. For a two-phase feed, where 80% of the feed is vaporized under column conditions, the feed line slope in the McCabe-Thiele method for distillation column design is
   a. $-¼$ b. $+¼$ c. + 4 d. – 4

6. If the percent humidity of air (30 °C, total pressure 100 kPa) is 24 % and the saturation pressure of water vapor at that temperature is 4 kPa, the percent relative humidity and the absolute humidity of air are
   a. 25.2, 0.0062 b. 20.7, 0.0055 c. 25, 0.0035 d. 18.2, 0.0035

7. At 25°C and 90 % relative humidity, water evaporates from the surface of a lake at the rate of 1 $kg/m^3.h$. The relative humidity that will lead to an evaporation rate of 3.0 $kg/m^2.h$ with other conditions remaining the same is
   a. 30 % b. 50 % c. 60 % d. 70 %

8. For a binary mixture of components A and B, N_A and N_B denote the total molar fluxes of components A and B, respectively. J_A and J_B are the corresponding molar diffusive fluxes. Which of the following is true for equimolar counter-diffusion in the binary mixture?
   a. $N_A + N_B = 0$ and $J_A + J_B \neq 0$ b. $N_A + N_B \neq 0$ and $J_A + J_B = 0$
   c. $N_A + N_B \neq 0$ and $J_A + J_B \neq 0$ d. $N_A + N_B = 0$ and $J_A + J_B = 0$

9. In a counter-current gas absorber, both the operating and equilibrium relations are linear. The inlet liquid composition and the exit gas composition are maintained constant. In order to increase the absorption factor
   a. the liquid flow rate should decrease
   b. the gas flow rate should increase
   c. the slope of the equilibrium line should increase
   d. the slope of the equilibrium line should decrease

10. In a binary mixture containing components A & B, the relative volatility of A with respect to B is 2.5 when mole fractions are used. The molecular weights of A & B are 78 & 92 respectively. If the compositions are however expressed in mass fractions, the relative volatility will then be
   a. 1.18 b. 2.12 c. 2.5 d. 2.95

11. Acetone is to be removed from air in an isothermal dilute absorber using pure water as solvent. The incoming air contains 5 mol% of acetone ($y_{in} = 0.05$). The design equation to be used for obtaining the number of trays (N) of the absorber is $N + 2 = 6\log(\frac{y_{in}}{y_{out}})$.
   For 98% recovery of acetone, the number of trays required is/are
   a. 1 b. 8 c. 9 d. 10

12. At a total pressure of one standard atm exerted by the vapors of water and toluene, the mole fraction of water x_w in the vapor phase satisfies
   a. $0 < x_w < 0.5$ b. $0.5 < x_w < 1.0$ c. $x_w = 0.5$ d. $x_w = 1.0$

13. In a tray column, separating a binary mixture, with non-ideal stages, which one of the following statements is true?
   a. Point efficiency can exceed 100%
   b. Murphree efficiency cannot exceed 100%
   c. Murphree efficiency can exceed 100%
   d. Both Murphree and point efficiencies can exceed 100%

14. For which of the following combinations, does the absorption operation become gas film controlled?
   P. The solubility of gas in the liquid is very high
   Q. The solubility of gas in the liquid is very low
   R. The liquid-side mass transfer coefficient is much higher than the gas-side mass transfer coefficient
   S. The liquid-side mass transfer coefficient is much lower than the gas-side mass transfer coefficient
   a. P & Q b. P & R c. P & S d. Q & R

15. Which of the following statement is **WRONG**?
   a. Steam distillation is used for mixtures that are immiscible with water.
   b. Vacuum distillation is used for mixtures that are miscible with water.
   c. Steam distillation is used for mixtures that are miscible with water.
   d. Vacuum distillation columns have larger diameters as compared to atmospheric columns for the same throughput.

16. The correct expression for the colburn factor for mass transfer that relates Sherwood number (Sh), Reynolds number (Re) and Schmidt number (Sc) is

a. $\frac{Sh}{(Re)(Sc)^{1/3}}$ b. $\frac{Sh}{(Re)^{1/2}(Sc)}$ c. $\frac{Sh}{(Re)^{1/2}(Sc)^{1/3}}$ d. $\frac{Sh}{(Re)(Sc)}$

17. If Prandtl number is greater than the Schmidt number, then the
   a. thermal boundary layer lies inside the concentration boundary layer
   b. concentration boundary layer lies inside the thermal boundary layer
   c. thermal & concentration boundary layers are of equal thickness
   d. hydrodynamic boundary layer is thicker than the other two

18. Which of the following is the **CORRECT** one?
   a. wet bulb temperature is always higher than dry bulb temperature
   b. wet bulb temperature is identical to dry bulb temperature at 0% relative humidity
   c. wet bulb temperature is identical to dry bulb temperature at 100% relative humidity
   d. dry bulb temperature is the temperature of adiabatic saturation

19. The relative volatility of a binary mixture at the azeotropic composition is

a. 1 b. < 1 c. > 1 d. ∞

20. Which of the following empirical equation dose denote the Freundlich adsorption curve?

a. $x.m = kp^{1/n}$ b. $\frac{x}{m} = kp^{\frac{1}{n}}$ c. $\frac{m}{x} = kp^{\frac{1}{n}}$ d. $\frac{x}{m} = k/p^{\frac{1}{n}}$

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SECTION "B"
[2 Q. × 5 = 10 marks]

Attempt *ALL* questions.

1. Mass transfer is occurring from a sphere of naphthalene to air at 45°C and 1 atm abs pressure flowing at velocity of 0.305 m/sec. The diameter of the sphere is 25.4 mm. The diffusivity of naphthalene in air at 45°C is 6.92×10^{-6} m^2/sec and the vapor pressure of solid naphthalene is 0.555 mm Hg. For gases for a Schimdt number range of 0.6 – 2.7 and a Reynolds number range of 1– 48000 , the following correlation can be used:

$$N_{Sh} = 2 + 0.552 N_{Re}^{0.53} N_{Sc}^{1/3}$$

Physical properties of air at 45°C:
$\mu = 1.93 \times 10^{-5}\ Pa.sec$
$\rho = 1.113\ kg/m^3$

a. Find the mass transfer coefficient k'_G. [3]
b. Also find the rate of mass transfer in terms of flux (Neglect the phenomena of size reduction of naphthalene ball with time). [2]

2. The vapor liquid equilibrium relation for an ideal binary system is given by

$$y_A^* = \frac{\alpha_{AB} x_A}{1 + (\alpha_{AB} - 1)x_A}$$

Here, x_A and y_A^* are the mole fractions of species A in the liquid and vapor, respectively. The relative volatility (α_{AB}) is greater than unity.

a. Show that, the liquid mole fraction x_A at which the maximum difference between the equilibrium vapor mole fraction and liquid mole fraction occurs is $\frac{1}{(1+\sqrt{\alpha_{AB}})}$ [3]
b. A liquid having the composition found in the part (a), is flash distilled at a steady state to a final liquid mole fraction of 0.25. If α_{AB} is 2.5, what would be the fraction of the feed vaporized? [2]

SECTION "C"

[3 Q. × 10 = 30 marks]

Attempt *ANY THREE* questions.

3. A tray tower (counter-current) is to be used to remove 99% of the ammonia from an entering air stream containing 6 mole % ammonia at 293K and 1.103×10^5 Pa. The entering pure water flow rate is 188 kg H_2O /h.m^2 and the inert air flow is 128 kg air/h.m^2. Calculate the number of theoretical trays required by graphical method (plot each and every point neatly and mention the exit concentrations).

Equilibrium data for water–ammonia system

Mole Fraction NH_3 in Liquid, x_A	*Partial Pressure of NH_3 in Vapor, p_A (mm Hg)*		*Mole Fraction NH_3 in Vapor, y_A; P = 1 Atm*	
	20°C (293 K)	*30°C (303 K)*	*20°C*	*30°C*
0	0	0	0	0
0.0126		11.5		0.0151
0.0167		15.3		0.0201
0.0208	12	19.3	0.0158	0.0254
0.0258	15	24.4	0.0197	0.0321
0.0309	18.2	29.6	0.0239	0.0390
0.0405	24.9	40.1	0.0328	0.0527
0.0503	31.7	51.0	0.0416	0.0671
0.0737	50.0	79.7	0.0657	0.105
0.0960	69.6	110	0.0915	0.145
0.137	114	179	0.150	0.235
0.175	166	260	0.218	0.342
0.210	227	352	0.298	0.463
0.241	298	454	0.392	0.597
0.297	470	719	0.618	0.945

Source: J. H. Perry, *Chemical Engineers' Handbook*, 4th ed. New York: McGraw-Hill Book Company, 1963. With permission.

4. A saturated liquid feed of 200 mole/h at the boiling point contains 42 % heptane and 58 % ethyl benzene is to be fractionated at 101.32 kPa absolute pressure to give a distillate containing 97 mole % heptane and a bottoms containing 1.1 mole % heptane. The reflux ratio used is 2.5:1.

a. Calculate the mole/h distillate. [1.5]
b. Calculate the mole/h bottom. [1.5]
c. Calculate the theoretical number of trays. [5]
d. Find the feed tray number. [2]

Equilibrium data for heptane-ethyl benzene is given below.

Temperature				Temperature			
K	$°C$	x_H	y_H	K	$°C$	x_H	y_H
409.3	136.1	0	0	383.8	110.6	0.485	0.730
402.6	129.4	0.08	0.230	376.0	102.8	0.790	0.904
392.6	119.4	0.250	0.514	371.5	98.3	1.000	1.000

5. Gas A diffuses from point 1 to a catalyst surface at point 2, where it reacts as follows: $2A \rightarrow B$. Gas B diffuses back a distance δ to point 1.
   a. Derive the equation for N_A for a very fast reaction using mole fraction unit x_{A1} and so on. [3]
   b. For $D_{AB} = 0.2 \times 10^{-4}$ m^2/sec, $x_{A1} = 0.97$, $P = 101.32$ kPa, $\delta = 1.30$ mm, and $T = 298$ K, solve for N_A. [2]
   c. Do the same part (a) but for a slow first order reaction, where k_1' is the reaction velocity constant. [3]
   d. Calculate N_A and x_{A2} for part (c) where $k_1' = 0.53 \times 10^{-2}$ m/sec. [2]

6. If 100 kg of a solution of acetic acid (C) and water (A) containing 30 % acid is to be extracted three times (cross-current) with isopropyl ether (B) at 20°C, using 40 kg of solvent in each stage,
   a. Determine the quantities and compositions of the various streams. [5]
   b. How much solvent would be required if the same final raffinate concentration were to be obtained with one stage? [5]

   The equilibrium data at 20°C is listed below. The horizontal rows give the concentrations in equilibrium solutions.

Water layer			Isopropyl ether layer		
Wt % acetic acid, $100x$	Water	Isopropyl ether	Acetic acid, $100y^*$	Water	Isopropyl ether
0.69	98.1	1.2	0.18	0.5	99.3
1.41	97.1	1.5	0.37	0.7	98.9
2.89	95.5	1.6	0.79	0.8	98.4
6.42	91.7	1.9	1.93	1.0	97.1
13.30	84.4	2.3	4.82	1.9	93.3
25.50	71.1	3.4	11.40	3.9	84.7
36.70	58.9	4.4	21.60	6.9	71.5
44.30	45.1	10.6	31.10	10.8	58.1
46.40	37.1	16.5	36.20	15.1	48.7

Instructions:

Questions 1, 2 & 4 require graph papers in order to solve.