KATHMANDU UNIVERSITY
End Semester Examination
June/July, 2023

Marks Scored:

Level : B.E.
Year : III

Course : CHEG 313
Semester : II

Exam Roll No. : Time: 30 mins. F. M. : 10

Registration No.: Date : 11 JUL 2023

SECTION "A"
[20 Q. × 0.5 = 10 marks]

Encircle the most appropriate answer.

1. The units of mass transfer coefficients could be______.
   a. Moles transferred/Time (area)(pressure)
   b. Moles transferred/Time (area) (mole fraction)
   c. Moles transferred/Time (area)(concentration)
   d. Any of these

2. According to the film theory the mass-transfer coefficient is directly proportional to____.
   a. D^2_{AB} b. $D^{0.5}_{AB}$ c. D_{AB} d. $D^{1.5}_{AB}$

3. According to the penetration theory, the mass-transfer coefficient is directly proportional to______.
   a. D^2_{AB} b. $D^{0.5}_{AB}$ c. $D^{1.5}_{AB}$ d. D_{AB}

4. The psychrometric ratio is defined as _______ where, h_G convective heat transfer coefficient, k_y is convective mass transfer coefficient and c_s is humid heat.
   a. h_G / k_y b. k_y / h_G c. $h_G / k_y \cdot c_s$ d. $k_y \cdot c_s / h_G$

5. In distillation where q is defined as the moles of liquid flow in stripping section per mole of feed introduced, for saturated liquid feed_________.
   a. q>1 b. q=1 c. q<1 d. q=0

6. Reboiler is considered as one theoretical plate, because___________.
   a. Of the assumption that vapor and liquid leaving the reboiler are in equilibrium
   b. Vapor is recycled to the column
   c. Reboiler itself contains one plate
   d. Vapor is pure

7. What is the humid heat of a mixture of air (C_p = 10 J) with water vapor (C_p = 20 J), if the humidity is 25%?
   a. 10 b. 15 c. 20 d. 25

8. The humidity at dry-bulb temperature of 20 °C is 40% and the humidity at dry-bulb temperature of 25 °C is 25%, what is the slope of adiabatic cooling line?
   a. -0.05 b. 0.05 c. -0.03 d. 0.03

9. ___________ is used to calculate the number of ideal theoretical stages for a given separation.
   a. Fenske equation b. Inverse lever arm rule
   c. Vapor Liquid Equilibrium d. McCabe Thiele

10. Minimum reflux ratio in a distillation column results in____________.

a. Optimum number of trays
b. Maximum condenser size
c. Minimum reboiler size
d. Minimum number of trays

11. Distillation used in the laboratories when the amount of required product is small______.

a. Steam
b. Fractional
c. Azeotropic
d. Batch

12. In a batch adsorption process, 5 g of fresh adsorbent is used to beat 1 liter on an aqueous phenol solution. The initial phenol concentration is 100 mg/L. The equilibrium relation is given by $q = 1.3C$, where q is the amount of phenol adsorbed in mg of phenol per gram of adsorbent and C is the concentration of phenol in mg/L in the aqueous solution. When equilibrium is attained between the adsorbent and the solution, the concentration of phenol in the solution is _________ mg/L.

a. 13.33
b. 7.5
c. 0.5
d. 11.11

13. A binary distillation column is to be designed using McCabe Thiele Method. The distillate contains 90 mol% of the more volatile component. The point of intersection of the q-line with the equilibrium curve is (0.5, 0.7). The maximum reflux ration for this operation is_________.

a. 2
b. 1.5
c. 0.5
d. 1

14. In a binary distillation column, if the feed contains 40 mol% vapor, the q line will have a slope of_________.

a. -0.6
b. 0.6
c. -1.5
d. 1.5

15. Find the diffusivity of AB in m^2/s if $J_A = 5$ $mol/m^2.sec$, concentration difference is 2 mol/m^3 and distance is 3 m.

a. 2.5
b. 5.5
c. 7.5
d. 10.5

16. At total reflux, ______.

a. Distillate is nil
b. Reflux is nil
c. Residue is nil
d. Maximum number of stages required

17. The distribution coefficient if equilibrium solute concentration in extract is 0.75 and the solute concentration in Raffinate is 0.6, would be______.

a. 0.8
b. 1
c. 1.25
d. 0

18. 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. 20.7, 0.0055
b. 25, 0.0035
c. 25.2, 0.0062
d. 18.2, 0.0035

19. In a binary mixture containing components A and B, the relative volatility of A with respect to B is 2.5 when mole fractions are used. The molecular weights of A and B are 78 and 92 respectively. If the compositions are however expressed in mass fractions, the relative volatility will then be______.

a. 1.18
b. 2.5
c. 2.12
d. 2.95

20. The correct expression for the Colburn factor for mass transfer that relates Sherwood number (Sh), Reynold number (Re) and Schmidt number (Sc) is______.

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

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Semester : II
F. M. : 40

SECTION "B
[5Q × 8 = 40 marks]

Attempt *ANY FIVE* questions.

1. The feed to a distillation column is a 45 mole % n-pentane and 55 mole % n-hexane liquid mixture. The vapor stream leaving the column, which contains 98 mole % pentane and the balance hexane goes to a total condenser. Half of the liquid condensate is returned to the top of the column and the rest is withdrawn as product at a rate of 85 kmol/hr. The overhead product contains 95 % of the pentane fed to the column. The liquid stream leaving the bottom of the column goes to a reboiler. Part of the stream is vaporized. The vapor is recycled to the bottom of the column and the liquid is taken off as a product as well. [n-pentane: MW = 72.15 g/mol and density = 0.621 kg/L and n-hexane: MW = 86.17 g/mol and density = 0.659 kg/L]
   a. What is the molar flow of the feed stream and the molar flow rate and composition of the bottom liquid stream? [4]

   b. What is the volumetric flow rates of the vapor leaving the column and the top liquid product if the temperature of the vapor as it enters the condenser assuming it is saturated at an absolute pressure of 1 atm is 37.3 °C? [4]

2. The SO2 emission limit at a plant is 25 ppmv. The concentration in the uncleaned exhaust gas is 200 ppmv. A packed absorption tower (a scrubber) of circular cross-section is currently used to reduce the SO2 concentration in the exhaust gas to 10 ppmv, i.e. well below the emission limit. The packed section of the scrubber has a height of 1 m. The solvent inlet concentration of SO2 is 0. A production increase is planned at the plant, and as a consequence of this, the exhaust gas flow rate is expected to increase by 30 %. It is assumed that the mass transfer coefficient will not be significantly affected be the increased flow rate, and no operational problems with the scrubber are expected to occur. The pollutant concentration in the solvent outlet stream is very low, and as a simplification it can be set to 0.
   a. Is it possible to keep the existing equipment and still have SO2 emissions below the emission limit after the production increase? (Hints: Check how HTUG will be affected by the production increase, simplify the NTUG equation and calculate a new NTUG while keeping Z constant.) [5]

   b. Are there potential operational bottlenecks, other than the emissions limit, that should be evaluated in connection with such a production increase? Explain. [3]

Henry's law: $y_A^* = \frac{H}{p} x_A$ $\quad z = HTU_G \cdot NTU_G$ $\quad HTU_G = \frac{G}{K_y a}$ $\quad K_y = \frac{1}{\frac{1}{k_y} + \frac{m}{k_x}}$ $\quad m = \frac{H}{p}$

$NTU_G = \int_{out}^{in} \frac{dy_A}{y_A - y_A^*}$ $\quad NTU_G = \frac{y_{A,in} - y_{A,out}}{(y_A - y_A^*)_{lm}}$ $\quad (y_A - y_A^*)_{lm} = \frac{(y_{A,in} - y_{A,in}^*) - (y_{A,out} - y_{A,out}^*)}{\ln \frac{y_{A,in} - y_{A,in}^*}{y_{A,out} - y_{A,out}^*}}$

3. Dry air at 17 °C and 1 atm is brought into contact with liquid water at the same temperature. The air can be assumed to contain 21 % O2 and 79 % N2.
(Use P°_{H2O} (T=290K) = 0.01917 bar)

a. Determine the mole fraction of H2O in the air at the interface between the gas and the liquid. [2]

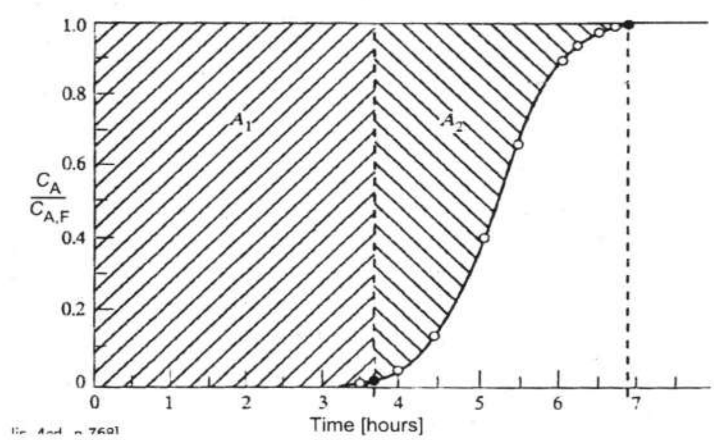
b. Determine the mole fraction of O2 in the air at the interface between the gas and the liquid. [4]

c. Determine the mole fraction of O2 in the water at the interface between the gas and the liquid. [2]

Table: Henry's constant [bars] for selected gases in water at moderate pressure.

T (K)	NH_3	Cl_2	H_2S	SO_2	CO_2	CH_4	O_2	H_2
273	21	265	260	165	710	22,880	25,500	58,000
280	23	365	335	210	960	27,800	30,500	61,500
290	26	480	450	315	1300	35,200	37,600	66,500
300	30	615	570	440	1730	42,800	45,700	71,600
310	—	755	700	600	2175	50,000	52,500	76,000
320	—	860	835	800	2650	56,300	56,800	78,600
323	—	890	870	850	2870	58,000	58,000	79,000

4. An adsorbate in vapor is adsorbed in an experimental packed bed. The inlet contains $C_{A,F}$ = 600 ppm of adsorbate. Assume 95% removal. Data measuring the outlet concentration over time from the bed are plotted below:



a. Determine the breakthrough time, t_b. [1]

b. What actual fraction of the bed's capacity is used at t_b? [1]

c. If the lab scale bed was originally 14 cm long, what equivalent length is unused at time t_b? [2]

d. If we wanted a breakthrough time of 7.5 hr instead, how much longer should the bed be (keeping the diameter and flow profile fixed)? [4]
$[t_b = t^*(1\text{-}LUB/L)][\, t^* \propto L]$

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5.

a. A large volume of pure gas B at 2 atm pressure is flowing over a surface from which pure A is vaporizing. The liquid A completely wets the surface, which is a blotting paper. Hence, the partial pressure of A at the surface is the vapor pressure of A at 298 K, which is 0.20 atm.

The k_y' has been estimated to be 6.78 $\times 10^{-5}$ kg mol/s $\cdot$ m^2 $\cdot$ mol frac. Calculate $N_A^{"}$, the vaporization rate, and also the value of k_y and k_G. (Hint: Use $k_{y=}$ k_y'/ y_{BM} where $y_{BM} = \frac{y_{B2}-y_{B1}}{\frac{y_{B2}}{y_{B1}}}$)($k_G$=$k_y$/P)($N_A^{"} = k_y(y_{A1}-y_{A2})$)($N_A^{"} = k_G(p_{A1}-p_{A2})$) [4]

b. Ammonia is stripped from a dilute aqueous solution by countercurrent contact with air in a column containing seven sieve trays. The equilibrium relationship is y_e=0.8x_e, and when the molar flow of air is 1.5 times that of the solution, 90 percent of the ammonia is removed. How many ideal stages does the column have, and what is the stage efficiency? [S = $\frac{mV}{L}$][N=$\frac{\ln[(x_a-x_a^*)/(x_b-x_b^*)]}{\ln S}$] [4]

6. Water exiting the condenser of a power plant at 45 °C enters a cooling tower with a mass flow rate of 15000 kg/s. A stream of cooled water is returned to the condenser from the cooling tower with the same flow rate. Make-up water is added in a separate stream at 20 °C. Atmospheric air enters the cooling tower at 30 °C with a wet bulb temperature of 20 °C. The volumetric flow rate of moist air into the cooling tower is 8000 m^3/s. Moist air exits the tower at 40 °C and 90% relative humidity. Assume an atmospheric pressure of 101.3 kPa. [$H_{y,sat} = c_s(T - 32) + \lambda_0 H_s$] [1ft equals 0.0283 m^3] [(0°C × 9/5) + 32 = 32°F] [λ_0=1075 Btu/lb]

a. the mass flow rate of dry air [4]

b. the temperature of the cooled liquid water exiting the cooling tower [4]