KATHMANDU UNIVERSITY
End Semester Examination [C]
November/December, 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 : 05 DEC 2023

SECTION "A"

[20Q. × 0.5 = 10 marks]

Choose and encircle the most appropriate answer.

1. Rate of adsorption increases as the
   a. Temperature decreases
   b. Temperature increases
   c. Pressure decreases
   d. Size of absorbent increases

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. The number of transfer units (NTU) is equal to the number of theoretical plates (NTP) only when the operating line
   a. Lies above the equilibrium line
   b. Lies below the equilibrium line
   c. And the equilibrium line are parallel
   d. Is far from the equilibrium line

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. Binary distillation involves the mass transfer by _____ at the gas-liquid interface.
   a. Unidirectional diffusion from liquid to gas phase
   b. Unidirectional diffusion from gas to liquid phase
   c. Non directional diffusion in either gas to liquid or liquid to gas phase
   d. A counter diffusion at an almost equal molar rate

9. Flooding in a column results due to
   a. High pressure drop
   b. Low pressure drop
   c. Low velocity of the liquid
   d. High temperature

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. Henrys' law states that the
    a. Partial pressure of a component over a solution is proportional to its mole fraction in the liquid
    b. Partial pressure of a component over a solution is proportional to its mole fraction in the vapor
    c. Vapor pressure is equal to the product of the mole fraction and the total pressure
    d. Partial pressure is equal to the product of the mole fraction and the total pressure

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. If the number and height of gas phase transfer units are 4.09 and 1.5 meters respectively, what is the tower absorption height ?
    a. 4.27 meters
    b. 2.37 meters
    c. 6.135 meters
    d. Insufficient data for calculation

18. The term "approach" in a cooling tower refers to the difference in the temperature of the
    a. Cold water leaving the tower and wet bulb temperature of the surrounding air
    b. Hot water entering the tower and wet bulb temperature of the surrounding air
    c. Hot water entering the tower and cooled water leaving the tower
    d. Cold air entering the tower and heated air leaving the tower

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. Unsaturated air with dry and wet bulb temperatures of 35 °C and 25 °C respectively is passed through water spray chamber maintained at 35 °C. The air will be
    a. Cooled
    b. Humidified
    c. Dehumidified
    d. Heated

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Year : III
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Course : CHEG 313
Semester : II
F. M. : 40

SECTION "B"
[5 Q. × 8 = 40 marks]

Attempt *ALL* questions.

1. a. A thin liquid film of ammonia, which has formed on the inner surface of a tube diameter D=10 mm and length 1 m is removed by passing dry air through the tube at a flow rate of $3 \cdot 10^{-4}$ kg/sec. The tube and the air are at 25 °C. What is the average mass transfer coefficient? Properties of air at 25 °C: $\nu = 15.7 \cdot 10^{-6}$ m²/s; $\mu = 183.6 \cdot 10^{-7}$ Ns/m² and $D_{AB} = 0.28 \cdot 10^{-4}$ m²/s. Show that the flow is laminar (Re < 2300) and use $Sh = A\left(\frac{Re.Sc}{L/D}\right)^n$ where A = 1.86 and n=1/3 for pipe flow cases. Sc= ν/ D_{AB} and $k_c = (Sh \cdot D_{AB})/D$. [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]

2. A mixture of 45 mole % n-hexane and 55 mole % n-heptane is subjected to continuous fraction in a tray column at 1 atm total pressure. The distillate contains 95 % n-hexane and the residue contains 5 % n-hexane. The feed is saturated liquid. A reflux ratio of 2.5 is used. The relative volatility of n-hexane in mixture is 2.36. Determine the number of ideal trays required.
($y = \frac{\alpha x}{1+(\alpha-1)x}$)($y = \left(\frac{R}{R+1}x + \frac{x_D}{R+1}\right)$ for rectifying section) ($y = \left(-\frac{q}{1-q}x + \frac{x_F}{1-q}\right)$ for feed) [8]

3. A gas mixture processed in an industrial ammonia production process contains 60 mol% H_2, 20 mol% N_2 and 20 mol% CO_2. Before the gas mixture is routed to the ammonia synthesis reactor (where H_2 and N_2 react to form NH_3), the CO_2 has to be separated from the other two gas components. At this particular plant, the separation will be done by absorption of CO_2 in water in an absorption tower. The pressure in the system is 24 bars, and the temperature is 280 K. The total gas flow rate is 700 mol/s. The mass transfer resistance in the gas phase and in the liquid phase can both be neglected (i.e. the surface concentrations are equal to the bulk concentrations). Hint: Use Henry's law and $HCO_2 = HCO_2$ (280K) = 960 bar and HH_2 (280K) = 61500).
   a. Estimate the minimum water flow rate (kg/s) required to absorb the CO_2 (neglecting absorption of other components) [5]
   b. Estimate the maximum loss (%) of H_2 from the gas phase to the liquid phase. [3]

4. Assume that the outside temperature is 32 °C with a relative humidity = 60 %. Use the psychrometric chart to determine the specific humidity, the enthalpy h, the wet bulb temperature T_{wb}, the dew-point temperature T_{db}, and the specific volume of the dry air, v. (Please submit your psychrometric chart along with your answer sheet with marked lines and values) [8]

5. The flow rate of exhaust gas from an industrial plant is 200 000 Nm^3/h. The gas, which can be considered an ideal gas, contains 70 % N_2, 10 % CO_2, 8 % H_2O and 12 % O_2 (mole basis). In addition, the gas contains HCl at a concentration of 100 ppmv (parts per million on a volume basis). The HCl emission limit is 10 mg/Nm^3 (dry gas at 10 % O_2). A packed absorption tower (a scrubber) of circular cross-section will be installed to reduce the HCl concentration to be in compliance with the emission limit. 7.6 cm Intalox saddles made of plastic will be used as packing elements. Above the packing material, an additional height of 20 % of the packing height is required for liquid distribution. Below the packing material, an additional height of 25 % of the packing height is required for the liquid sump. The temperature in the system is 300 K, and the inlet pressure is 1.1 bar. The specific surface of the column packing is 100 m^2/m^3, the overall mass transfer coefficient based on the gas side is 1 $mol/(m^2s)$, and the superficial gas velocity at the bottom of the tower is 2.5 m/s. Henry's constant can be set to 3 bar (constant). The absorption liquid is approximated as water with a viscosity of 0.005 g/(cm·s), a molecular mass of 18 g/mol and a density of 1000 kg/m^3. The absorption liquid entering at the top of the absorption tower is pure (contains no HCl), and the liquid feed rate is 0.15 m^3 per kmol of gas.

a. Make a sketch of the system, including all relevant symbols, units and values. [2]
b. What is the diameter of the tower [m]? [1]
c. What is the required cleaning efficiency (%) to be in compliance with the emission limit? [3]
d. What is the concentration of HCl (mol/m^3) in the absorption liquid leaving the scrubber? [2]

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

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