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CHEMICAL ENGINEERING REFRESHER COURSE

UNIT OPERATIONS PART 2

Problems 1 and 2 are based on the following information:

A packed countercurrent cooling tower experiment has humid air flow rate of 1700 gpm, diameter of 1.5-ft, and humid air inlet temperature of 60 °F at 10% RH. The value of $K'_y a$ is 1.70 kg/m^3-s while the slope of the tie line is 9 kJ/kg for a liquid to gas ratio of 1.0.

1. Determine the NTU of the tower.
   a. 1.47
   b. 2.47
   c. 3.47
   d. 4.47

2. Calculate the height of the packed tower.
   a. 3.55 ft
   b. 5.89 ft
   c. 4.47 ft
   d. 2.26 ft

Problems 3 to 5 are based on the following information:

A dryer produces 450 lb_m/hr of product containing 8% wt water in wet basis when the feed contains 126% wt water in dry basis. Supply air to the dryer is at 212 °F, 100 °F dew point while leaving air is at 150 °F, 60% RH. Part of the leaving air is mixed with the fresh air supplied at 70 °F, 50% RH ahead of the heater. Neglecting the heat lost by radiation and used in heating the solid, conveyor trays, etc.

3. What is the air requirement of the dryer (dry basis) in lb_m/hr?
   a. 5000
   b. 5700
   c. 6000
   d. 6700

4. What is the heat requirement in BTU/hr of the dryer only?
   a. 347,400
   b. 733,400
   c. 344,700
   d. 433,700

5. How much heat in BTU/hr is supplied to the heater only?
   a. 275,200
   b. 525,700
   c. 252,700
   d. 725,200

6. Which of the following materials and configurations in a through-circulation dryer will have the longest drying time?
   a. granular silica gal from 82% to 18% wt moisture at 52 °C with an air velocity of 91 m/s
   b. extruded kaolin from 31% to 0.8% wt moisture at 102 °C with an air velocity of 101.6 m/s
   c. granulated lead arsenate from 56% to 5% wt moisture at 132 °C with an air velocity of 220 m/s
   d. scored filter cake of starch potato from 46% to 6% wt moisture at 127 °C with an air velocity of 102 m/s

7. Estimate the liquid film mass transfer coefficient in kg mol/m^2-s of a 0.25-m flat plate of solid benzoic acid. The plate has a flowing pure liquid water with velocity of 0.03 m/s and the diffusivity of benzoic acid in water at 20 °C is 1.25×10^{-9} m^2/s.
   a. 2.60×10^{-6}
   b. 2.60×10^{-4}
   c. 4.11×10^{-4}
   d. 1.44×10^{-4}

8. Estimate the gas film mass transfer coefficient in kg mol/m^2-s of a 15-mm ID wetted wall column. The column with air velocity of 7.25 m/s is used to absorb dilute ethanol in air, which has a mass diffusivity of 0.145 cm^2/s at 40 °C and 1 atm.
   a. 1.34×10^{-3}
   b. 4.31×10^{-3}
   c. 4.13×10^{-3}
   d. 1.43×10^{-3}

9. Estimate the liquid film mass transfer coefficient in kg mol/m^2-s of a 64-mm ID pipe. The pipe inner wall has a very thin layer of polymer with dissolved radon gas, wherein it diffuses to the flowing pure liquid water with velocity of 0.25 m/s. The diffusivity of radon in water is 4.30×10^{-6} cm^2/s at 5 °C and 1 atm.
   a. 8.22×10^{-4}
   b. 2.88×10^{-4}
   c. 2.05×10^{-6}
   d. 5.20×10^{-6}

10. Estimate the gas film mass transfer coefficient in kg mol/m^2-s of a 3-ft ID countercurrent absorption column. The column with random packings of 1-in Berl saddles is used to absorb dilute ammonia in air. The liquid and gas mass flow rates in the column are 7900 and 1600 lb_m/hr, respectively. Note that the effective interfacial mass transfer area per unit volume is 2.5 ft^{-1}.
   a. 0.0140
   b. 0.0410
   c. 0.0104
   d. 0.0401

Problems 11 and 12 are based on the following information:

Gas, from a petroleum distillation column, has a concentration of H_2S reduced from 0.03 (kmol H_2S/kmol of inert hydrocarbon gas) to 1% of this value by scrubbing with a triethanolamine-water solvent in a countercurrent tower, operating at 300 K and atmospheric pressure. The equilibrium relation for the solution may be taken as $Y_e = 2X$. The solvent enters the tower free of H_2S and leaves containing 0.013 kmol H_2S/kmol solvent. The flow of inert gas is 0.015 kmol/m^2-s and the overall coefficient for absorption $K_G a$ may be taken as 0.04 kmol/m^3-s (unit mole fraction driving force).

11. What is the total height of the absorber?
   a. 5.9 m
   b. 4.2 m
   c. 2.4 m
   d. 7.8 m

12. What is the number of overall gas-phase mass-transfer units?
   a. 21
   b. 20
   c. 15
   d. 12

Problems 13 to 15 are based on the following information:

A tower packed with Flexipac Type 2y structured packing (FP2Y) is to be used to remove 99.5% of the ammonia from an air stream containing an ammonia mole fraction of 0.005. The tower is to operate isothermally at 100 °F and 1 atm. The ammonia is to be absorbed in an aqueous solution of nitric acid. The tower diameter has been selected to give an F factor of 2.0 (ft/s)(lb_m/ft^3) and a liquid loading of 15 gal/min. The density of air stream is 0.0709 lb_m/ft^3 and that of water is 62 lb_m/ft^3.

13. What is the liquid to gas ratio (L/G) from calculating the molar fluxes of the gas and liquid?
   a. 7.25
   b. 6.25
   c. 5.25
   d. 4.25

14. What concentration of acid should be used to ensure that the maximum absorption rate is obtained throughout the entire tower?
   a. 0.0192 M
   b. 0.0912 M
   c. 0.0473 M
   d. 0.0743 M

15. What is the height of the packing for physical absorption at the same conditions?
   a. 6.78 ft
   b. 6.96 ft
   c. 6.86 ft
   d. 6.68 ft

Problems 16 to 18 are based on the following information:

450 lbmol/hr of mixture of 60% mol benzene and 40% mol toluene is to be separated at 1 atm into a liquid distillate and a liquid bottoms product of 95% and 5% mol, respectively. The feed enters the column with a molar percent vaporization equal to the distillate-to-feed ratio.

16. What is the slope of the q-line?
    a. 0.46
    b. 0.93
    c. 0.39
    d. 0.64

17. If R/R_{min} = 1.3, what is the slope of the rectifying-section operating line?
    a. 4.16
    b. 0.62
    c. 1.59
    d. 0.41

18. Determine the number of equilibrium stages to achieve the desired separation.
    a. 14
    b. 13
    c. 12
    d. 11

19. What temperature will form an azeotrope for a mixture of chloroform and acetone at 1 atm?
    a. 823 °R
    b. 758 °R
    c. 154 °R
    d. 147 °R

20. Is it possible for Murphree vapor efficiency to be greater than 100%?
    a. Yes, small column diameter promotes more stream mixing
    b. Yes, mixing of liquid and gas streams is less in each tray
    c. Yes, some components may be entrained in the gas phase
    d. No, equilibrium concentration is the maximum concentration

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