GATE PSUs

State Engg. Exams

MADE EASY

Workbook 2024

Detailed Explanations of Try Yourself *Questions*

Chemical Engineering

Mass Transfer

MADE EASY PUBLICATIONS

1 Diffusion, Mass Transfer Coefficient and Basic Theories for Mass Transfer Coefficients

Detailed Explanation *of* Try Yourself Questions

T1 : Solution

(0.5286)

$$V_{H2} = 14.3 \text{ and } M_{H2} = 2$$
$$V_{\text{air}} = 29.9 \text{ and } M_{\text{air}} = 28.9$$

From kinetic theory of gases, where D in cm^2/sec.

$$D = 435.7\frac{T^{3/2}}{P(V_A^{1/3}+V_B^{1/3})^2} = \left(\frac{1}{M_A}+\frac{1}{M_B}\right)^{1/2}$$

$$435.7\frac{(298)^{3/2}}{(1.01325\times10^5)[14.3^{1/3}+29.9^{1/3}]^2}$$

$$\times\left[\frac{1}{2}+\frac{1}{28.9}\right]^{1/2} = 0.5286 \text{ cm}^2/\text{sec}$$

T2 : Solution

(0.0536 m/sec)

Colburn's j - factor for heat transfer

$$j_H = \frac{f}{2} = (St)_H \cdot P_r^{2/3}$$

From heat and mass transfer analogy, Colburn's factor for mass transfer is

$$j_M = (St)_M \cdot Sc^{2/3} = \frac{f}{2}$$

From these results we know $j_H = j_M$

$$(St)_H P_r^{2/3} = (St)_M Sc^{2/3} = \frac{f}{2}$$

$(St)_H$ Stanton number for H.T. $= \dfrac{h_x}{\rho u_\infty C_p}$

$$(St)_M \text{ Stanton number for M.T.} = \frac{k_m}{u_\infty}$$

$$\frac{h_x}{\rho u_\infty C_p} P_r^{2/3} = \frac{k_m}{u_\infty} Sc^{2/3}$$

$$k_m = \frac{h_x}{\rho C_p}\left(\frac{P_r}{Sc}\right)^{2/3}$$

$$k_m = \frac{56.8}{1.2 \times 1.005 \times 10^3}\left(\frac{0.74}{0.61}\right)^{2/3} = 0.0536 \text{ m/sec}$$

T3 : Solution

(7.29×10^{-6})

Effective diffusivity of a component in mixture is given by

$$D_{\text{eff}} = \frac{1}{\sum \frac{y_i}{D_{C_i}}} = \frac{1}{\left(\frac{y_O}{D_{CO}}\right) + \left(\frac{y_N}{D_{CN}}\right)}$$

From KTG, diffusivity is proportional to $\frac{T^{3/2}}{P}$ then $(D_1)_{CO}$ diffusivity of O_2 w.r.t. CO is at temperature 310 K and 3 atm.

$$\frac{D_{2CO}}{D_{1CO}} = \left(\frac{T_2}{T_1}\right)^{3/2}\left(\frac{P_1}{P_2}\right)$$

$$18.5 \times 10^{-6} = D_{1CO} \times \left(\frac{273}{310}\right)^{3/2} \times 3$$

$$D_{1\,CO} = 18.5 \times 10^{-6} \times \left(\frac{310}{273}\right)^{3/2} \times \frac{1}{3} = 7.46 \times 10^{-6} \text{ m}^2\text{/sec}$$

Diffusivity of N_2 w.r.t. CO is at temperature 310 K and 3 atm is

$$D_{1\,CN} = 19.5 \times 10^{-6} \times \left(\frac{310}{288}\right)^{3/2} \times \frac{1}{3} = 7.25 \times 10^{-6} \text{ m}^2\text{/sec}$$

Composition of O_2 and N_2 on a carbon monoxide free basis is

$$y_O = \frac{0.18}{1 - 0.1} = 0.2$$

and $$y_N = \frac{0.72}{1 - 0.1} = 0.8$$

The effective diffusivity of carbon monoxide is

$$D_{\text{eff}} = \frac{1}{\left(\frac{0.2}{7.46 \times 10^{-6}}\right) + \left(\frac{0.8}{7.25 \times 10^{-6}}\right)} = 7.29 \times 10^{-6} \text{ m}^2\text{/sec}$$

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2 Absorption, Stripping and Packed Tower Design

Detailed Explanation of Try Yourself Questions

T1 : Solution

(2.5 ft)

Height of an overall liquid phase transfer unit is

$$H_{OL} = H_{tl} + \frac{L_s}{mG_s} H_{tg}$$

$$H_{OL} = 0.9 + \frac{1800}{18 \times 1.5 \times 50} \times 1.2$$

$$H_{OL} = 2.5 \text{ ft}$$

T2 : Solution

(0.0375)

$$Y_1 = 0.03, \quad Y_2 = 0.0003$$

and

$$X_2 = 0, \quad X_1 = 0.013$$

$$G_s = 0.015 \text{ kmol/m}^2\text{-sec}$$

$$\text{Height of tower} = 7.79 \text{ m}$$

Number of transfer unit

$$\text{NTU} = \frac{\ln\left[\frac{(Y_1 - mX_2)}{Y_2 - mX_2}\left(1 - \frac{1}{A} + \frac{1}{A}\right)\right]}{\ln(A)}$$

$$\text{NTU} = \frac{\ln\left[\frac{0.03}{0.0003}\left(1 - \frac{1}{1.142}\right) + \frac{1}{1.142}\right]}{\ln(1.142)}$$

$$= 19.50$$

where, $$A = \frac{L_s}{mG_s} = \frac{0.0342}{2 \times 0.015} = 1.142$$

$$G_s(Y_1 - Y_2) = L_s(X_1 - X_2)$$

$$0.015\,(0.03 - 0.003) = L_s \times 0.013$$

$$L_s = 0.0342$$

$$\text{Height of tower} = \text{NTU} \times \text{HTU}$$

$$\text{HTU} = \frac{\text{Height of tower}}{\text{NTU}} = \frac{7.79}{19.50} = 0.399 \text{ m}$$

$$\text{HTU} = \frac{\frac{G_s}{A_C}}{K_G \cdot aP_t} = \frac{0.015}{K_G \cdot a(1)}$$

$$K_G \cdot a = \frac{0.015}{0.399} = 0.0375 \text{ kmol/atm. m}^3 \text{ sec}$$

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3 Distillation

Detailed Explanation of Try Yourself Questions

T1 : Solution

(38)

$$V' = 29.5$$
$$R_{min} = 0.98$$
$$R_{internal} = 0.98 \times 1.3 = 1.274$$
$$R_{internal\ reflux} = \frac{L}{V}$$
$$L = R \times V$$
$$= 1.274 \times 29.5 = 37.583 \simeq 38$$

T2 : Solution

(a)

$$P_A^V = 0.1 \text{ bar}, \quad P_B^V = 1.8 \text{ bar}$$
$$\frac{\eta_A}{\eta_B} = \frac{P_A^V}{P_B^V} = \frac{\text{mole of 'A'}}{\text{mole of 'B'}}$$
$$\frac{\eta_A}{\eta_B} = \frac{E P_A^V}{P_B^V}$$

where E is vaporization efficiency.

$$\text{mole of 'A'} = \frac{5}{180} = 0.027 \text{ kmol}$$
$$\text{mole of 'B' } (\eta_B) = \frac{\eta_A \cdot P_B^V}{E P_A^V} = \frac{0.027 \times 1.8}{0.85 \times 0.1}$$
$$= 0.588 \text{ kmol}$$

$$\text{Mass of steam} = 0.588 \times 18 = 10.58 \text{ kg steam}$$

$$\text{Steam rate} = 10 \text{ kg/hr}$$

$$\text{Time required} = \frac{10.58}{10} = 1.05 \text{ hr}$$

Correct option is (a).

T3 : Solution

(1)

Intersection point of rectifying and stripping section is at $x = 0.5$ and $y = 0.625$. The feed is an equimolar mixture ($x = 0.5$) so the feed line is vertical and feed is saturated liquid.

$$\text{Value of } 'q' = 1$$

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4 Humidity (Humidification, Cooling Tower)

Detailed Explanation of Try Yourself Questions

T1 : Solution

(30.12%)

Since the first droplet of water condenses at 15°C and 200 kpas, at this conditions the air is 100% humidity.

$$\text{Percentage humidity} = \frac{P_A}{(P_t - P_A)} \times \frac{P_t - P_A^S}{P_A^S} \times 100$$

$$= 100$$

$$\frac{P_A}{P_t - P_A} = \frac{P_A^S}{P_t - P_A^S}$$

Molal humidity of water vapor per mole of dry air = $\frac{1.7051}{200 - 1.7051} = 0.0086$ and it is constant, so P_A at 30°C is

$$\frac{P_A}{P_t - P_A} = 0.0086, \quad \frac{P_A}{150 - P_A} = 0.0086$$

$$P_A = 1.279 \text{ kPa}$$

$$\%\text{ relative humidity} = \frac{P_A}{P_A^{sat}} \times 100$$

$$= \frac{1.279}{4.246} \times 100 = 30.12\%$$

T2 : Solution

(26.29°C)

$$T - T_w = \frac{(Y_w' - Y')\lambda}{\frac{h}{k_Y}}$$

where, $Y' = 0,\ \lambda = 360$ kJ/kg

$$\frac{h}{k_Y} = 2 \text{ kJ/kg.K and } T_w = 7.6°\text{C}$$

$$Y_w' = \frac{5}{101.3 - 5} \times \frac{58}{29} = 0.1038$$

$$T - 7.6 = \frac{360 \times (0.1038 - 0)}{2}$$

$$T = 7.6 + 18.69 = 26.29°\text{C}$$

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5 Liquid-Liquid Extraction and Adsorption

Detailed Explanation *of* Try Yourself Questions

T1 : Solution

(20.58) [20 to 21]

If the desired separation is to be performed by using the minimum quantity of clay, the system must reach equilibrium at the end of the treatment.

Mass balance:

$$L_S(Y_i - Y_F) = W_{min} X_F^*$$

where,

$$X_F^* = \frac{Y_F}{4.2 \times 10^{-4}}$$

$$= \frac{1}{4.2 \times 10^{-4}} = 2380.95$$

$$L_S = 1000 \text{ then}$$

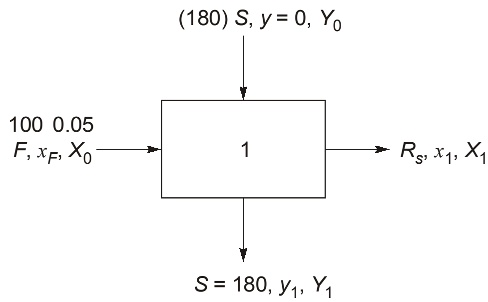
$$1000\,(50 - 1) = W \times 2380.95$$

(Minimum quantity of adsorbent in kg)

$$W_{min} = 20.58 \text{ kg}$$

T2 : Solution

(a)



$$R_s = F_s = 95$$
$$R_s = 100\,(1 - 0.05) = 95$$

Mass balance on mixer settler

$$R_S X_0 + S \cancel{Y_0}^{\,0} = R_S X_1 + S Y_1$$
$$95\, X_0 = 95\, X_1 + 180\, Y_1$$
$$5 = 95\, X_1 + 180 \times 0.8\, X_1$$
$$\frac{5}{239} = X_1 = 0.0209$$

$$\text{Amount in raffinate phase} = 95\, X_1 = 1.9874 \text{ kg}$$

Percentage extraction of acetone

$$= \frac{5 - 1.9874}{5} \times 100 = 60.28$$

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6 Drying and Leaching

Detailed Explanation of Try Yourself Questions

T1 : Solution

(1 kg)

Rate of drying at constant rate period

$$N_C = K_G \Delta \bar{P}_A = K_G(\bar{P}_A{}^* - \bar{P}_A)$$

$\bar{P}_A{}^*$ = Partial pressure of water vapor at equilibrium

$\bar{P}_A$ = Partial pressure of water vapor in drying air

K_G = Mass transfer coefficient

$$N_C = 5.34 \times 10^{-4} (4232 - 2360) = 1 \text{ kg/hr.m}^2$$

T2 : Solution

(16.2 hrs)

$$\text{Initial moisture } X_i = \frac{0.2}{0.8} = 0.25, \quad \text{Final moisture } X_F = \frac{0.05}{0.95} = 0.0526$$

Time required in constant rate period

$$\theta_C = \frac{S_S}{N_C A_C}(X_i - X_c) = -\frac{S_S}{A_C}\int_{X_i}^{X_C} \frac{dX}{N_C}$$

$$\theta_C = 45.8 \times (0.25 - 0.193) \times 0.8196 = 2.139 \text{ hr}$$

Time required in falling rate period

$$\theta_F = -\frac{S_s}{A_c}\int_{X_C}^{X_F} \frac{dX}{N} = 45.8 \times 0.307 = 14.06 \text{ hr}$$

$$\text{Total time } \theta = \theta_C + \theta_F = 16.2 \text{ hrs}$$

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