

Mass Transfer –I

19CH4DCMT1

4th Semester

Question Bank

**Department of Chemical
Engineering
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Course: Mass Transfer-1

Course Code: 19CH4DCMT1

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Unit 1: Diffusion Numerical

- (1) Ammonia and air are in equimolar diffusion in a cylindrical tube of 3.5 mm diameter and 25 m length. The total pressure is 1 atmosphere and the temperature is 27°C. One end of the tube is connected to a large reservoir of ammonia and the other end of the tube is open to the atmosphere. If the mass diffusivity for the mixture is $0.3 \times 10^{-4} \text{ m}^2/\text{s}$, calculate the mass transfer rates of ammonia and air through the tube.
- (2) A well located in the desert is 10 m deep to the water level and 1 m in diameter. The stagnant air and the water in the well are at 32°C and 1 atm pressure. A slight breeze of dry air is blowing across the top of the well. Calculate the rate of diffusion in kg/s at steady state from the surface of water in the well. The partial pressure of water vapour in the air at the surface of the water is 45 mmHg. The diffusivity of water in air at 32°C and 1 atm is $0.06 \text{ m}^2/\text{h}$.
- (3) Hydrochloric acid (A) at 283°K diffuses through a thin film of water (B) 4 mm thick. The concentration of A at location 1 on the one boundary of the film is 12 wt.% (density, $\rho_1 = 1060.7 \text{ kg/m}^3$). The diffusivity of HCl in water is $2.5 \times 10^{-9} \text{ m}^2/\text{s}$. Calculate the flux of diffusion of A assuming water to be stagnant (i.e., non-diffusing).
- (4) In an $\text{O}_2\text{--N}_2$ mixture at 10 atm and 25°C the concentration of O_2 at two places 0.2 cm apart are 20 and 30 vol.% respectively. Calculate the rate of diffusion of O_2 expressed as $\text{g/cm}^2 \text{ h}$ for the case of uni-component diffusion. Value of diffusivity of O_2 in N_2 is $0.181 \text{ cm}^2/\text{s}$.
- (5) Calculate the rate of diffusion of HCl across a film of non-diffusing water 0.3 cm thick at 20°C when the concentration on either side the film are 10% and 5% by weight acid respectively. The diffusivity of HCl in solution is $1.25 \times 10^{-4} \text{ m}^2/\text{s}$. The specific gravity of 10% and 5% HCl are 1.013 and 1.008 respectively. Average molecular weight of 10% and 5% HCl are 18.9 and 18.3 respectively.



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(6) Calculate the rate of diffusion of NaCl at 18°C through a stagnant film of water 1 mm thick, when the concentrations are 20% and 10% respectively on either side of the film.

Data: Density of the solution at phase 1 in 1112 kg/m³, Density of solution at phase 2 in 1003 kg/m³, D_{AB} is 1.26×10^{-9} m²/s and molecular weight of NaCl is 58.5 kg/kmol.

(7) Calculate the rate of diffusion of acetic acid (CH₃COOH) at 18°C through a stagnant film of water 2 mm thick, when the concentrations are 9 and 3 weight % respectively on either side of the film. The densities of 9% and 3% acid solutions are 1012 kg/m³ and 1003 kg/m³ respectively. Diffusivity of acetic acid in water, D_{AB} is 0.95×10^{-9} m²/s.

(8) Ammonia gas (A) is diffusing through a uniform tube 0.1 m long containing N₂ gas (B) at 101325 Pa pressure and 298 K. At point 1, $\bar{p}_{A1} = 1.013 \times 10^4$ Pa and at point 2, $\bar{p}_{A2} = 0.507 \times 10^4$ Pa. The diffusivity D_{AB} is 0.23×10^{-4} m²/s. Compute (i) Flux J_A at steady state and (ii) Repeat for J_B .

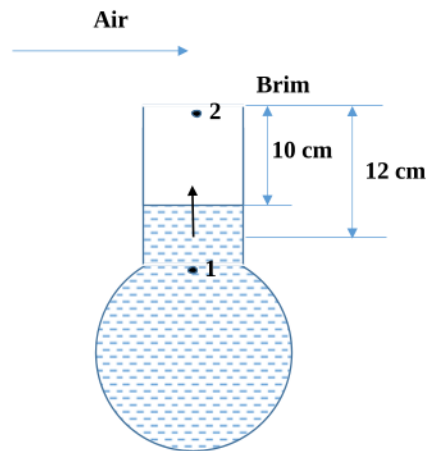
(9) Calculate the rate of diffusion of water vapour from the surface at the bottom of the well 6 m deep to dry air flowing at the top of the well. The system is at 1 atm and 298 K. If the well diameter is 3 m, find the total amount of water evaporated per second. The diffusivity of water vapour in air is 0.256×10^{-4} m²/s. Partial pressure of water vapour in air at 298 K is 0.0316 bar. Vapour pressure of water at 298K is 0.0317 bar.

(10) Find the rate of diffusion of oxygen under equi-molal counter-current diffusion in a gas mixture of oxygen and nitrogen between two planes 0.5 m apart with 10 and 20% concentration of oxygen at the planes. Data: temperature = 30°C, pressure = 1 bar and $D_{AB} = 0.181$ cm²/s.

(11) The apparatus shown in the following figure is kept at 40°C and 1 atm pressure. The air is circulated so that the concentration of water vapour in the air is zero. If 29 hours are needed for the level to fall down from 10 cm to 12 cm below the brim of the tube, what is the diffusivity of water in air? Vapour pressure of water at 40°C is 120 mmHg.



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(12) Ammonia is diffusing under steady state conditions through a layer of stagnant air film 10 mm thick. The gas mixture contains 15% NH_3 by volume on one side of stagnant layer. The diffused NH_3 on the other side is immediately absorbed in water. The system is at 30°C and 1 atm, diffusivity of NH_3 in air is $60 \text{ cm}^2/\text{h}$. How much NH_3 is absorbed in 6 h?

(13) A moth ball in the shape of 1.9 cm diameter sphere is suspended in still air. The pressure and temperature are 1 atm and 74°C respectively. In a period of 24 h, how much of moth ball enters the gas phase? Use the following data: molecular weight = 128 g/mol, vapour pressure at 74°C = 5 mmHg and $D_{AB} = 0.078 \text{ cm}^2/\text{s}$ at given temperature and pressure.

(14) Hydrogen gas at 17°C and 0.01 atm partial pressure is diffusing through a Neoprene membrane 0.5 mm thick. The partial pressure of H_2 gas on other side of membrane is zero. If solubility (S) of H_2 in Neoprene is 0.051 m^3 (at 0°C , 1 atm)/ m^3 of solid atm and diffusivity at 17°C (D_{AB}) is $1.03 \times 10^{-10} \text{ m}^2/\text{s}$. Calculate steady state flux of rate of diffusion through membrane.

(15) An ethanol (A) – water (B) solution in form of a stagnant film 2 mm thick at 20°C is in contact on one side of surface with an organic solvent in which ethanol is soluble and water is insoluble ($N_B = 0$). At point 1 the concentration of ethanol is 16.8% and solution density is $988.1 \text{ kg}/\text{m}^3$. If the diffusivity of ethanol is $0.74 \times 10^{-9} \text{ m}^2/\text{s}$ calculate the steady state flux, N_A in $\text{kmol}/\text{m}^2\text{s}$.

(16) The diffusivity of the gas pair $\text{O}_2 - \text{CCl}_4$ is determined by observing the steady state evaporation of CCl_4 into a tube containing oxygen. The distance between the CCl_4 liquid level and the top of the tube is 17.1 cm. The pressure and temperature were 755 mmHg and 0°C . It is found that 0.0208 cc of CCl_4 evaporated in a 10 h period after steady state is



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reached. Data: cross sectional area of the tube = 0.82 cm^2 , vapour pressure of CCl_4 at 0°C = 33 mmHg, density of CCl_4 liquid = 1590 kg/m^3 . Estimate the diffusivity of $\text{O}_2 - \text{CCl}_4$.

(17) Water level in a 1 m diameter well in a desert is 12 m deep from surface. The stagnant air and water in well are at a pressure of 750 mmHg and 30°C respectively. A gentle breeze of air is blowing across top of well. Calculate loss of water in kg/h due to steady state diffusion from surface of water. Data: diffusivity for air – water system at 30°C and 1 atm pressure is $2.6 \times 10^{-5} \text{ m}^2/\text{s}$ and vapour pressure of water at 30°C = 0.045 atm.

(18) A sphere of Naphthalene (C_{10}H_8) having a radius 2 mm is suspended in a large volume of still air at 318 K and 1 atm. The surface temperature of sphere can be assumed to be at 318 K. Evaluate rate of sublimation due to diffusion in $\text{kg/m}^2\text{h}$. Data: vapour pressure of naphthalene in air is $6.92 \times 10^{-6} \text{ m}^2/\text{s}$.

(19) An oxygen (A) – Nitrogen (B) gas mixture at two planes 0.2 m apart is at one atm pressure and 25°C , with concentration of solute (A) of 15% and 25% by volume. The diffusivity for the mixture is $1.81 \times 10^{-5} \text{ m}^2/\text{s}$. Calculate the rate of diffusion when there is (i) equimolar counter diffusion and (ii) B non-diffusing.

(20) Calculate the rate of diffusion of NaCl at 20°C through a stagnant film of water 2 mm thick, when the concentrations are 20% and 10% respectively on either side of the film. Densities of 20% and 10% NaCl are 1.15 and 1.05 g/cc respectively. Diffusivity of NaCl is $0.18 \times 10^{-6} \text{ m}^2/\text{s}$.

(21) Ammonia gas is diffusing at a constant rate through a layer of stagnant air 1 mm thick. Conditions are fixed so that the gas contains 50% by volume of ammonia at one boundary of the stagnant layer. The ammonia diffusing to the other boundary is quickly absorbed and the concentration is negligible at that place. The temperature is 295 K and the pressure is atmospheric and under these conditions the diffusivity of ammonia in air is $0.18 \text{ cm}^2/\text{s}$. Calculate the rate of diffusion of ammonia through the layer. If equimolar counter diffusion is occurring in the above case, what would be the percent change in the rate of diffusion?

(22) The diffusivity of toluene in air is measured by Stefan's method. A vertical glass tube of 3 mm diameter is filled with toluene to a depth of 19 mm from the top open end. After 275 h and 37°C and 1 atm total pressure, the level has fallen to 79 mm from the top. The density



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of toluene is 850 kg/m^3 and its vapour pressure at 37°C is 57.3 mmHg . Neglecting counter diffusion of air to replace the liquid calculate the diffusivity of toluene into air at this condition.

(23) Oxygen diffuses through a non-diffusing gas mixture of methane and hydrogen in the volume ratio of 3:1. The diffusivities are estimated to be $D_{\text{O}_2-\text{H}_2} = 6.99 \times 10^{-5}$ and $D_{\text{O}_2-\text{CH}_4} = 1.86 \times 10^{-5} \text{ m}^2/\text{s}$. The total pressure is $1 \times 10^{-5} \text{ N/m}^2$ and the temperature 0°C . The partial pressure of oxygen at two planes 2 mm apart is 26,000 and 13,000 N/m^2 respectively. Calculate the rate of diffusion of oxygen in kmol/s through each square meter of two planes.

(24) A well, 6 m in depth, 3 m in diameter contains a thin layer of water at its bottom at 1 atm, 25°C . A slight breeze of dry air is blowing across the top of the well. Find the rate of water evaporated from the well in kg/h . The diffusion coefficient of water vapour in air at 1 atm, 25°C is $2.56 \times 10^{-5} \text{ m}^2/\text{s}$.

(25) In mass transfer equipment, benzene is transferred from air to a non-volatile oil at 300 K and 1 atm. At a certain point in the equipment, the benzene mole fraction in the bulk of the gas phase is 0.02, while the corresponding interfacial benzene gas-phase mole fraction is 0.0158. The benzene flux at that point is found as $0.00795 \text{ mol/m}^2 \text{ s}$. Calculate the mass transfer co-efficient in the gas phase at that point expressing the driving force (i) in terms of mole fraction (ii) in terms of molar concentrations and (iii) in terms of partial pressure. At the same place in the equipment, the benzene mole fraction in the bulk of the liquid phase is 0.125. Then (iv) calculate the mass transfer co-efficient in the liquid phase at that point expressing the driving force in terms of mole fractions. (v) What is the percent resistance in gas phase? Equilibrium data can be taken as $y^* = 0.1x$, where x and y are the mole fractions of benzene in the liquid and gas phase respectively.

(26) Solute A is absorbed from a gas mixture of A and B with liquid flowing as thin film downward along the wall of a tower. At a certain point in the tower, the bulk gas concentration is 0.38 mole fraction and bulk liquid concentration is 0.1 mole fraction. Solute A is moving and B is stagnant in the gas phase and get absorbed in a non-diffusing liquid. Use the equilibrium data and find the interface compositions in both liquid and gas phase. Considering the solution to be dilute, estimate flux conditions. Data is given as follows.



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x_A	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35
y_A	0	0.022	0.052	0.087	0.131	0.181	0.265	0.385

$k_y = 1.465 \times 10^{-3}$ kmol/m² s mole fraction and $k_x = 1.967 \times 10^{-3}$ kmol/m² s mole fraction

(27) In a wetted-wall tower, where NH₃ was absorbed in water, the overall gas co-efficient K_G was found to be 1 kmol/h m² atm. At one point in the column, the gas contained 8 mol% NH₃ and the liquid phase concentration was 0.064 kmol/m³. Pressure and temperature were 1 atm and 20°C. 85% of the total resistance to the mass transfer was found to be in the gas phase. The equilibrium relationship is $p_A = 0.01248C_A$, where p_A is in atm; C_A in kmol/m³.

Determine:

- The overall liquid co-efficient
- The (individual) film co-efficients
- The interfacial compositions
- p_A^* and C_A^*
- The molar flux of NH₃

(28) In an absorption operation, the bulk concentrations of solute in the gas and liquid phase at a particular location are 2 mol% and 0.5%, respectively. The equilibrium relation over this concentration range may be taken as $y^* = 2.5x$. If the two phases are offering equal mass-transfer resistances, find the solute concentration on either side of the gas-liquid interface.



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Unit 2: Humidification

Instructions:

- 1. Know the use of steam table and humidity chart**
- 2. Know all the formulae**
- 3. Use of ideal gas law for density**
- 4. Units should be taken care**

- 1 The vapor pressure of benzene is found to be 100 mmHg at 26°C and 400 mmHg at 60.6°C. At what temperature is the vapor pressure 200 mmHg?
- 2 In a mixture of benzene vapor (A) and nitrogen gas (B) at a total pressure of 800 mmHg and a temperature of 60°C, the partial pressure of benzene is 100 mmHg. Express the benzene concentration in other terms
 - a) Mole fraction
 - b) Volume fraction
 - c) Absolute humidity
- 3 A gas benzene mixture is saturated at one standard atmosphere at 50°C. Calculate the absolute humidity if B is 1) Nitrogen 2) Carbon monoxide

Data: partial pressure of benzene at 50°C = 275 mmHg
- 4 An air (B) – water vapor (A) sample has a dry bulb temperature 55°C and absolute humidity $0.030 \frac{\text{kg of water vapour}}{\text{kg dry air}}$ at 1 standard atmospheric pressure. Tabulate its characteristics:
 - a) Molal absolute humidity
 - b) Partial pressure of water vapor
 - c) Dewpoint
 - d) Humid volume
 - e) Enthalpy
- 5 If 100 m³ of moist air of 0.974 humid volume is heated to 110°C, how much heat is



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required? Related to previous question.

- 6 A mixture of air and water-vapor has a dry bulb temperature of 60°C and an absolute humidity of $0.03 \frac{\text{kg of water vapour}}{\text{kg dry air}}$. The system pressure is at 1 atmosphere absolute. Evaluate.
- a) Saturation absolute humidity
 - b) Relative humidity/relative saturation
 - c) Dewpoint temperature
 - d) Humid volume
 - e) Humid heat
 - f) Enthalpy
 - g) Heat required to heat 1.2 m^3 of this mixture to 120°C
 - h) Adiabatic saturation temperature
 - i) Wet bulb temperature
- 7 Air at 83°C , $Y' = 0.03 \frac{\text{kg water vapor}}{\text{kg of dry air}}$, 1 standard atmospheric pressure is contacted with water at adiabatic saturation temperature (AST) and is thereby humidified and cooled to 90% saturation. What are the final temperature and humidity of air?
- 8 $0.6 \text{ m}^3/\text{s}$ of gas is to be dried from a dewpoint of 294 K to a dewpoint of 277.5 K . How much water must be removed and what will be the volume of the gas after drying? The vapor pressure of the water vapor at 277.5 K is 0.85 kN/m^2 and at 294 K is 2.5 kN/m^2 .
- 9 Conditioned air at 760 mmHg total pressure, 50°C and at a humidity of $0.01 \frac{\text{kg of water vapour}}{\text{kg bone dry air}}$ enters the drier. It leaves the drier at 760 mmHg total pressure and 50°C , with RH 83%. Vapor pressure of water at 50°C is 92.5 mmHg . If 50 kg of water enters into the air stream per hour, calculate the rate of bone-dry air flowing through the dryer.
- 10 $30,000 \text{ m}^3$ of coal gas measures at 298 K and 1 atm is saturated with water vapor. This



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is compressed to 340 kN/m^2 pressure and cooled to 298 K and the condensed water is drained off. Subsequently, the pressure is reduced to 170 kN/m^2 and the gas is distributed at this pressure and 98 K . What is the relative humidity after treatment? The vapor pressure of water at 298 K is 1.8 kN/m^2

- 11 In a vessel at 1 bar and 300 K , the % RH of water vapor in the air is 25 . If the partial pressure of water vapor when the air is saturated with vapor at 300 K is 3.6 kN/m^2 . Calculate
- The partial pressure of water
 - The absolute humidity of air
 - The percentage humidity
 - The humid volume
- 12 Air at a temperature of 20°C and a pressure of 750 mmHg has a relative humidity of 80%
- Calculate the molal absolute humidity of the air
 - Calculate the molal humidity of the air if its temperature is reduced to 10°C and its pressure is increased to 2.5 atm , condensing out some water.
 - Calculate the weight of water condensed from 100 m^3 of original wet air in cooling and compressing to the condition of part 'b'
- 13 Air at a temperature of 40°C and atmospheric pressure has wet bulb temperature of 30°C .
- Estimate the molal humidity, the percentage saturation and dew point of this air.
 - The air of part 1 is passed into a humidifier from which it emerges having a dry bulb temperature of 50°C and wet bulb temperature of 45°C . Estimate the percentage saturation of the air leaving the humidifier and calculate the weight of water gained per 1000 m^3 of air entering.
- 14 Liquid water and air are flowing into a humidification chamber in which water evaporates completely. The entering air contains 1 mole percent of water vapor and 20.8% of oxygen and the rest nitrogen. The humidified air should contain 10 mole percent of water. Calculate the flow rate of liquid humidify 20 kg mol/min of entering



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the air.

- 15 The percentage humidity of air at 30°C and a total pressure of 750 mmHg is 20%. Calculate the RH and partial pressure of water vapor in the air. What is the dew point of the air?
- 16 Humid air at 75°C, 1.1 bar and 30% RH is fed to a processing unit at a rate of 1000 m³/h. Determine the molal humidity, the percentage humidity, and absolute humidity.
- 17 At 297 K and 1 bar, the mixture of nitrogen and benzene has the relative humidity 60%. It is required to recover 80% of benzene present by cooling to 283 K and compressing to a suitable pressure. What is that pressure?

Vapor pressure of benzene at 297 K = 12.2 kN/m²

Vapor pressure of benzene at 283 = 6 kN/m²

- 18 In a vessel at 1 bar and 300 K, the relative humidity of water vapor in the air is 25%, if the partial pressure of water vapor when air is saturated with vapor at 300 K is 3.6 kN/m², calculate the following
- the partial pressure of water
 - the humidity of the air
 - percentage humidity
 - humid volume.
19. Air contains 0.015 kg water vapor per cubic meter of mixture at 303 K and 101.3 kPa. Determine the following.
- The partial pressure of water vapor
 - The relative saturation
 - The absolute humidity
 - The percent saturation
 - The temperature to which the mixture to be heated so that the percent saturation becomes 10%

The vapor pressure of water (in kPa) is approximated by Antoine equation, where T in



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K.

$$\ln p^S = 16.26205 - \frac{3799.887}{(T - 46.857)}$$

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Unit 3: Drying

1. A batch of wet solids is to be dried from 35% to 10% moisture under constant drying conditions in five hours. If the equilibrium moisture content is 4% and the critical moisture content is 14%, estimate the time required to dry the solids to 6% moisture under the same conditions. All moisture content are on the wet basis.
2. A 100 kg batch of granular solids containing 30% moisture is to be dried in a tray drier to 16% moisture by passing a current of air at 350 K tangentially across its surface at a velocity of 2 m/s. If the constant rate of drying under these conditions is 0.7×10^{-3} kg/m²s and the critical moisture content is 15%, calculate the time required for drying. Data: drying surface 0.03 m²/kg dry weight
3. Slabs of paper pulp 100 cm × 100 cm × 1.5 cm are to be dried under constant drying conditions from 67% to 30% moisture. The equilibrium moisture for the material is 0.5%. If the critical moisture content is 60% and the rate of drying at the critical point is 1.5 kg/m²s, calculate the drying time. The dry weight of each slab is 2.5 kg. All the moisture contents are on the weight basis. The falling rate may be assumed to be linear.
4. A batch of solid is to be dried from 28% to 6% moisture on wet basis. The initial weight of the solid is 380 kg and the drying surface is 0.15 m²/40 kg dry weight. The critical moisture content is 18% on a dry basis and the constant drying rate is 0.32 kg/m²h. For the falling rate period, the following data are available.

Moisture content, % dry basis	25	21.9	19	16	13.6	11	8.2	7.5	6.4
Rate of drying, kg/m ² h	0.3	0.27	0.24	0.21	0.18	0.15	0.07	0.044	0.025

5. It is desired to dry a sheet material from 55% to 4% moisture content. The sheets are 125 cm by 140 cm by 5 cm. The drying rate during the constant rate period is 1.5 g/cm²h. The critical moisture content is 26% and the equilibrium moisture content is



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negligible. If the material is dried from both sides and has a bone dry density of 4000 kg/m^3 , estimate the time required for drying assuming the falling rate to be linear. All moisture contents are on the wet basis.

6. 1400 kg (bone dry) of a granular solid is to be dried under constant drying conditions from moisture content of $0.2 \text{ kg/kg dry solid}$ to a final moisture content of $0.02 \text{ kg/kg dry solid}$. The drying surface is given as $0.0615 \text{ m}^2/\text{kg dry solid}$. Under the same conditions, the following rates were previously known. Estimate the time required for drying.

Moisture content	0.3	0.2	0.14	0.096	0.056	0.046	0.026	0.016
$X = \text{kg/kg dry solid}$								
Rate of drying, $\text{kg/m}^2\text{h}$	1.71	1.71	1.71	1.46	1.26	0.88	0.54	0.376

7. It is desired to dry a certain type of fiber board in sheets. The sheet size is 1.2 m by 2 m by 12 mm . In order to determine the drying characteristics of these sheets, a 0.3 m by 0.3 m sample of the board, with the edges sealed, so that the drying took place from the two large faces, was suspended from a balance in a laboratory cabinet dryer. In the dryer it was exposed to a current of hot, dry air. The initial moisture content was 75% . The sheet lost weight at the constant rate of $1 \times 10^{-4} \text{ kg/s}$ until the moisture content fell to 60% , after which the drying rate fell. Measurements of the rate of drying were discontinued, but after a long period of exposure of the sheet to this hot air it was established that the equilibrium moisture content was 10% . The dry mass of the sample was 0.9 kg . All the moisture contents are on the wet basis. Determine the time for drying the large sheets from 75 to 20% under the same drying conditions. Assume that the falling rate to be linear with free moisture content.
8. A porous solid is dried in a batch dryer under constant drying conditions. Seven hours are needed for reducing the moisture content from 35 to 10% . The critical moisture content was found to be 20% and the equilibrium moisture content was 4% . All the moisture contents are on the dry basis. Assuming that the rate of drying during the falling rate period is proportional to the free moisture content, find the



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time required to dry a sample of the same solid from 35 to 5% on dry basis under the same drying conditions.

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Unit 4: Adsorption and Ion Exchange

1. A valuable solute is present in an aqueous solution is removed by adsorption on a decolorizing carbon. Series of experiments yield the following data:

kg carbon/kg solution	0	0.001	0.004	0.008	0.02	0.04
Equilibrium color	9.6	8.1	6.3	4.3	1.7	0.7

The color should be reduced to 10% of its original value 9.6. Find the quantity of fresh carbon required per 100 kg of solution in a single-stage and two stage cross-current operations.

2. The equilibrium adsorption of acetone vapor on activated carbon at 30°C is given by,

g adsorbed/g carbon	0	0.1	0.2	0.3	0.35
Partial pressure of acetone, mmHg	0	2.0	12.0	42.0	92.0

A liter flash contains air and acetone vapor at 1 atm and 30°C with partial pressure of acetone 100 mmHg. Two grams of fresh activated carbon is introduced into the flask, and it is sealed. Compute the final vapor concentration at 30°C and the pressure inside the flask. Neglect the adsorption of air.

3. Experiments on decolourization of oil yielded the following equilibrium relationship.

$$b = 0.5a^{0.5}$$

Where, a = color in oil (g of color/1000 g of color-free oil) and b = g of color removed/g of adsorbent. 100 kg oil containing 1 part of color to 3 parts of oil is agitated with 25 kg of the adsorbent. Calculate the percentage of color removed if,

(a) 25 kg of adsorbent is used in one step and (b) 12.5 kg adsorbed is used initially, followed by another 12.5 kg of adsorbent.



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4. A waste water solution having a volume of 2.5 m^3 contains $0.25 \text{ kg phenol/m}^3$ of solution. This solution is mixed thoroughly in a batch process with 3 kg of fresh granular activated carbon until equilibrium is reached. Calculate the final equilibrium values and percent phenol extracted.

Equilibrium data

C , kg phenol/ m^3 solution	0.322	0.117	0.039	0.0061	0.0011
q , kg phenol/kg carbon	0.150	0.122	0.094	0.059	0.045

5. A solution of washed, raw cane sugar, 48% sucrose by weight, is colored by the presence of small quantities of impurities. It is to be decolorized at 80°C by treatment with an adsorptive carbon in a contact filtration plant. The data for an equilibrium adsorption isotherm were obtained by adding various amounts of the carbon to separate batches of the original solution and observing the equilibrium color reached in each case. The data, with the quantity of carbon expressed on the basis of the sugar content of the solution, are as follows:

kg carbon/kg dry sugar	0	0.005	0.01	0.015	0.02	0.03
Color removed, %	0	47	70	83	90	95

The original solution has a color concentration of 20, measured on an arbitrary scale, and it is desired to reduce the color to 2.5% of its original value.

- (a) Convert the equilibrium data to $Y^* = \text{color units/kg sugar}$, $X = \text{color units/kg carbon}$. Do they follow the Freundlich equation? If so, what are the equation constants?
- (b) Calculate the necessary dosage of fresh carbon, per 1000 kg of solution, for a single stage process. (Ans. 20.4 kg)
- (c) Calculate the necessary carbon dosages per 1000 kg of solution for a two-stage crosscurrent treatment, using the minimum total amount of fresh carbon. (Ans. 10.54 kg)
- (d) Calculate the necessary carbon dosage per 1000 kg of solution for a two-stage



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counter-current treatment. (Ans. 6.24 kg)

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Crystallization: Unit 5

- 1) An aqueous solution of sodium sulfate containing 28% Na_2SO_4 is cooled to 20°C and left undisturbed so that $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ crystals are formed. Calculate how much crystals will be deposited from a 500 kg original solution. What will be the yield of crystallization? Data: the solubility of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ at 20°C is 19.4 kg/100 kg H_2O .
- 2) Calculate the yield of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ crystals when 1000 kg of saturated solution of MgSO_4 at 80°C is cooled to 30°C assuming 10% of the water is lost by evaporation during cooling. Data: solubility of MgSO_4 at 80°C = 64.2 kg/100 kg water and at 30°C = 40.8 kg/100 kg water.
- 3) A hot solution containing 1000 kg of MgSO_4 and water having concentration of 30 weight% of MgSO_4 is cooled to 288.8 K, where crystals of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ are precipitated. The solubility at 288.8 K = 24.5 weight% of anhydrous MgSO_4 in the solution. Calculate the yield of crystals obtained if 5% of the original water is lost due to evaporation loss.
- 4) 5000 kg/h of a solution of NaNO_3 , containing 16 mol NaNO_3 per 1000 g of water is cooled from 90°C to 40°C . During the crystallization process, 3% of the total solution evaporates. Calculate (i) the yield of crystals (ii) heat to be removed. Solubility: 12.3 mol/1000 g; heat of crystallization = 21,000 kJ/kmol of NaNO_3 ; and specific heat of feed, $C_p = 2.47$ kJ/kg K.
- 5) An aqueous solution of sodium sulfate containing 28% Na_2SO_4 is cooled to 20°C and left undisturbed so that $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ crystals are formed. Calculate how much crystals will be deposited from a 500 kg original solution. What will be the yield of crystallization? Data: the solubility of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ at 20°C is 19.4 kg/100 kg H_2O .
- 6) A saturated solution of MgSO_4 at 90°C is cooled to 30°C in an evaporative crystallizer whose 10% material present is evaporated. Calculate the quantity of original solution to be used for the production of 19,000 kg of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$. Solubility of MgSO_4 at 90°C = 68.2 g/100 g of water and at 30°C = 40.8 g/100 g of water.
- 7) A salt solution weighing 10,000 kg with 30 wt.% Na_2CO_3 containing is cooled at 293 K (20°C). The salt crystallizes as a decahydrate. What will be the yield of $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ crystals if the solubility is 21.5 kg anhydrous Na_2CO_3 per 100 kg of total water at 20°C ? Do this for the following cases. (i) assume that no water evaporates (ii) assume that 3% of the total weight of the solution is lost by evaporation of water in cooling.



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- 8) A saturated solution of MgSO_4 at 90°C is cooled to 30°C in an evaporative crystallizer where 10% of water present is evaporated. Calculate the quantity of original solution to be used for the production of 19,000 kg of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$. Data: solubility of MgSO_4 at 90°C = 68.2 kg/100 kg water and at 30°C = 40.8 kg/100 kg water.
- 9) 150 kg of saturated solution of AgNO_3 at 100°C is cooled to 20°C and the crystals are filtered out. The wet filter cake which contains 80% solid crystals and 20% saturated solution by mass passes to a dryer in which the remaining water is removed. Calculate the fraction of AgNO_3 in the feed stream recovered as dry crystals and the amount of water that must be removed in the drying stage. Solubility of AgNO_3 at 100°C = 952 g/100 g water and at 20°C = 222 g/100 g water.
- 10) A solution of potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) in water contains 13% $\text{K}_2\text{Cr}_2\text{O}_7$ by weight. From 1000 kg of this solution, 640 kg of water evaporated. The remaining solution is cooled to 20°C . Estimate the amount and the percentage yield of $\text{K}_2\text{Cr}_2\text{O}_7$ crystals produced. Solubility of $\text{K}_2\text{Cr}_2\text{O}_7$ at 20°C is 0.39 kg moles/1000 kg of water.
- 11) At 20°C the solubility of NaCl in water is 36 parts/100 parts and that of NaNO_3 is 88 parts/100 parts. At this temperature a saturated solution containing both salts has 25 parts NaCl and 59 parts NaNO_3 per 100 parts water. At 100°C the individual solubility of NaCl and NaNO_3 are 40 and 176 parts/100 parts water. A saturated solution of both salts at 100°C contains 17 parts NaCl and 160 parts NaNO_3 per 100 parts water. Evaluate yield of NaNO_3 crystals when the saturated solution at 100°C is cooled to 20°C .
- 12) A saturated solution of KCl containing 1000 kg solids at 90°C is cooled to 20°C . Determine the yield of crystals, if the solubility of KCl at 90°C = 53 parts/100 parts of water and the solubility of KCl at 20°C = 34.5 parts/100 parts of water.
- 13) A batch of 1000 kg of KCl is dissolved in sufficient water to make a saturated solution at 353 K, where the solubility is given as 54 parts of KCl per 100 parts of water. (i) What is the weight of water required? (ii) What is the yield of crystals if the above solution is cooled to 293 K, if 5% of the original water evaporates on cooling? At 293 K the solubility of KCl is 0.456 g mol of KCl per 100 g of water.
- 14) Calculate the yield of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ crystals when 1000 kg of saturated solution of MgSO_4 at 80°C is cooled to 30°C assuming 10% of the water is lost by evaporation during cooling.



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$$\text{Solubility of MgSO}_4 \text{ at } 80^\circ\text{C} = \frac{64.2 \text{ kg}}{100 \text{ kg water}}$$

$$\text{Solubility of MgSO}_4 \text{ at } 30^\circ\text{C} = \frac{40.8 \text{ kg}}{100 \text{ kg water}}$$

- 15)** An aqueous solution of sodium sulphate containing 28% Na_2SO_4 is cooled to 20% crystals left undisturbed so that $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ crystals are formed. Calculate the crystals formed from 500 kg of original solution. What will be the yield of crystallization?

Data: the solubility of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ at 20°C is $\frac{19.4 \text{ kg}}{100 \text{ kg H}_2\text{O}}$.

- 16)** A simple vacuum crystallizer is to produce 4540 kg/hr of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ crystals. The feed is a solution containing 38.9 parts per 100 parts of water, at 70°C . The crystallizer temperature is 27°C . Neglecting BPR, determine the amount of feed solution required.

The solubility at 27°C is 30.2 parts per 100 parts water.

Enthalpy values: feed solution: +109.2 kJ/kg, crystals: -214.2 kJ/kg and saturated solution (at 27°C): -5.5 kJ/kg.

Molecular weight of FeSO_4 : 151.9

- 17)** A hot solution containing 1000 kg of MgSO_4 and water having concentration of 30 wt.% of MgSO_4 is cooled to 288.8 K, where crystals of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ are precipitated. The solubility at 288.8 K = 24.5 wt.% of anhydrous MgSO_4 in the solution. Calculate the yield of crystals obtained, if 5% of the original water is lost due to evaporation loss.



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