Polymer Process Engineering
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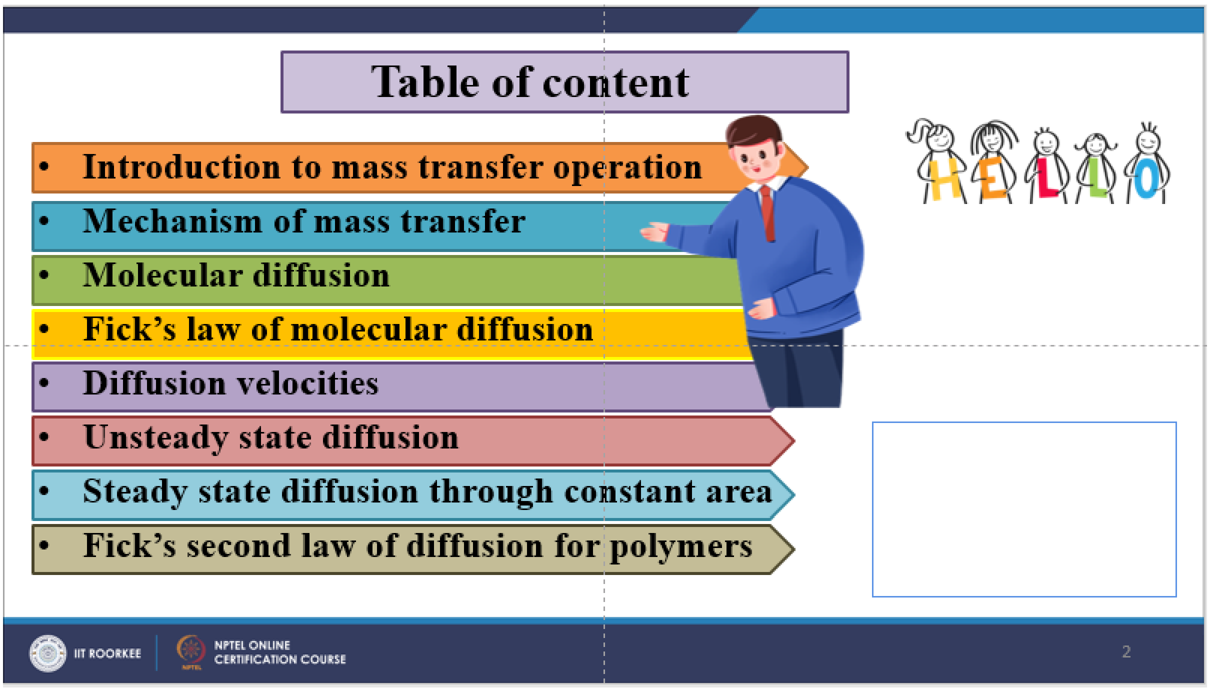
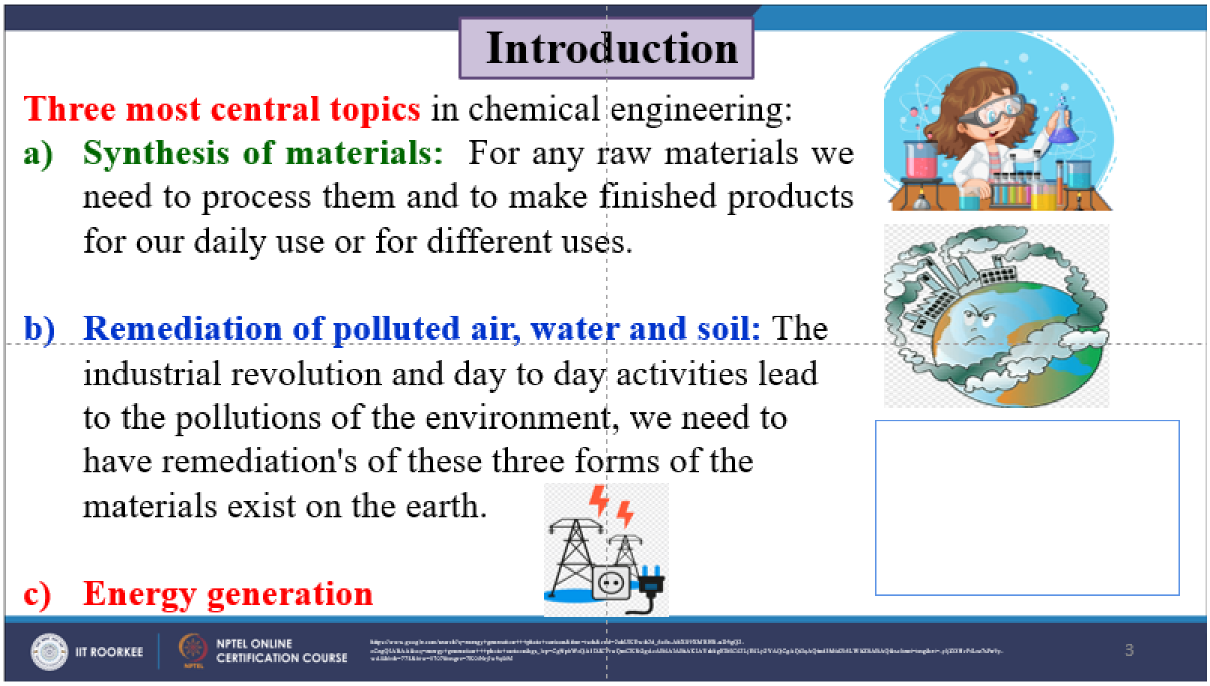
Lecture – 21
Mass transfer phenomenon in polymers: Introduction

Hello friends, welcome to the mass transfer phenomena in the polymeric systems. So, dear friends in this particular segment, we are going to discuss about the mass transfer operation. Then we will discuss about the mechanism of mass transfer, then the molecular diffusion, we will discuss about the Fick's law of molecular diffusion, then diffusion velocity is unsteady state diffusion, the steady state diffusion through the constant area. Then we will discuss about the Fick's second law of diffusion for polymers.



Now, there are three most you can say the central topic in chemical engineering and they are equally applicable in the polymeric system. Like one is the synthesis of material for any raw material, we need to process them and to make the finished product for our commodity use or day to day use or for the different industrial or specialized use.



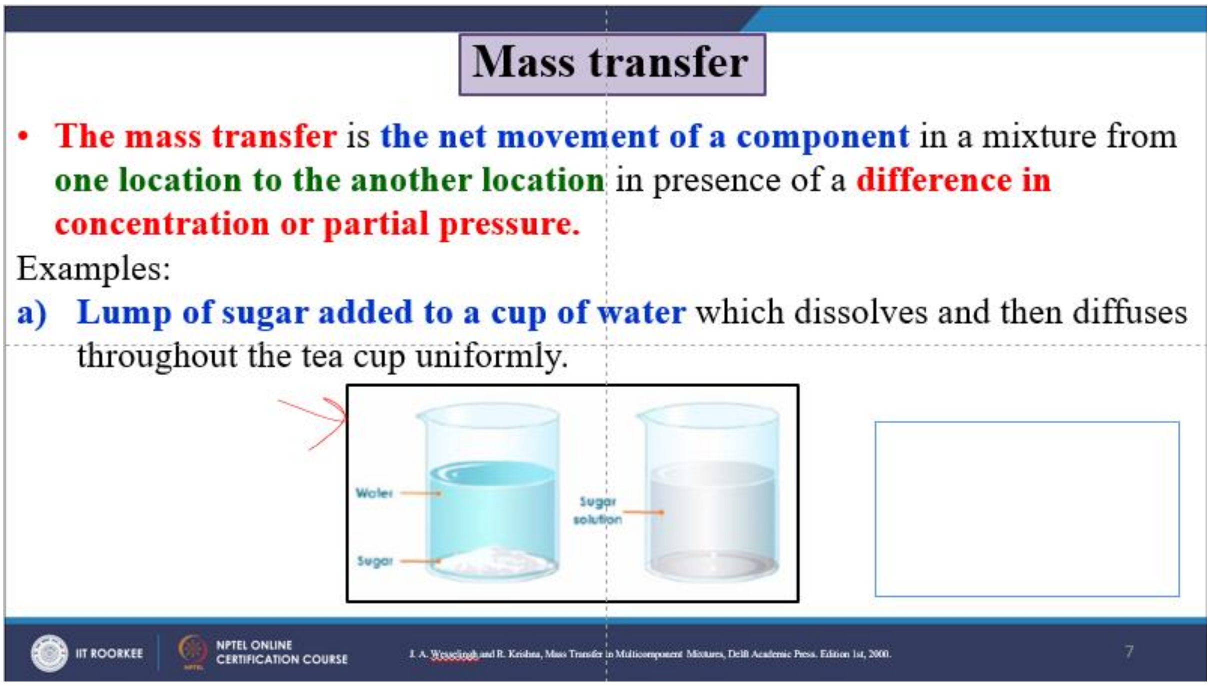
So, once you are having the specified quantity and a specification of the raw material, then there is a process and this process converts all these raw material into the useful product. Then second one is the remediation of the polluted air, water and soil. The industrial revolution and a day to day activity is led to the pollution of the environment and we need to have a remediation of these three forms of the material exist on the earth. First is the energy generation.

Now separation of the chemical mixtures into their constituent is being practiced for long time. The reason is that because sometimes you cannot have 100 percent conversion. So, if you are having a reaction mass, then there may be some unreacted component, there may be some by-product, there may be some product which are desired. So, you need to separate all those things. Apart from this nature has given so many things and you need to separate all those useful things from that particular segment, which is again the under the edges of the separation of the chemical mixture.

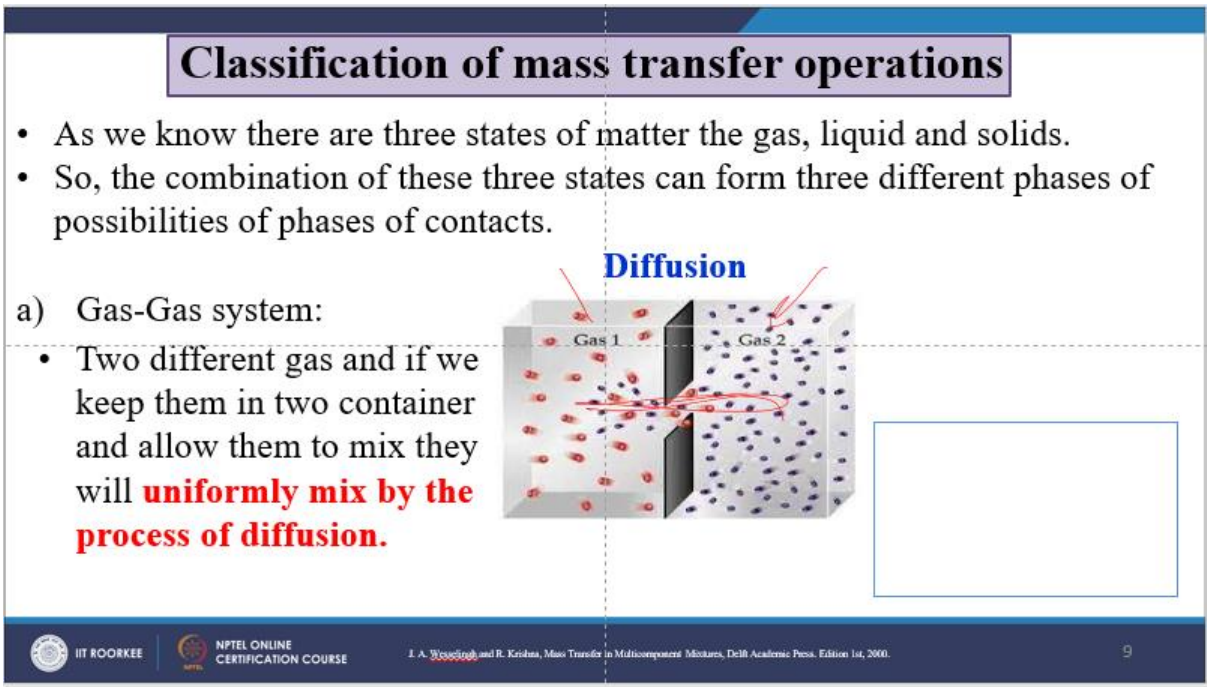
Now, there are various verticals for these separation protocols. One is the extraction of the metal from ores like perfume from the flowers and dyes from plant, then evaporation of the seawater to generate the salt, the production of distilled liquid through the separation process. All these are the example of the separation process. Now in chemical industries, there are chemical reactors and then separators. So, the chemical reactors they are the central feature but in terms of the cost, the separation cost dominates over the chemical reactors because ultimately, we our main intention is to get the useful product in a purified form or the form which is described as per the specification you need to get it.

That is why when it separates it out, it added to the cost of the product. The separation cost is directly dependent on the final to the initial concentration of this substance. So, for this the ratio is large and the product cost is large. For example, the pure uranium cost is much higher because in nature it found is much less quantity in a lower concentration. So, to purify and to produce a pure product is it involves a huge separation cost, whereas the production of the sulfuric acid is much cheaper.

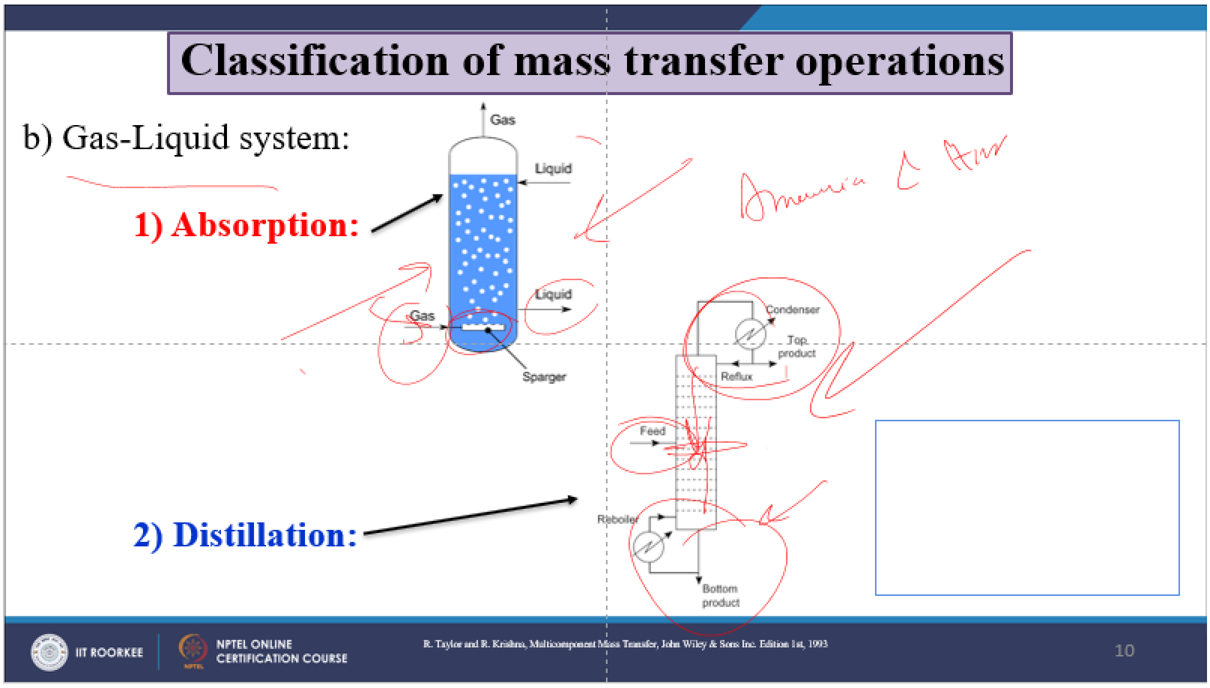
Now, there are various separation protocols, which are based on either entirely the separation of different particles, grids or different particle sizes, usually maybe by the screening, maybe by other separation protocols or the filtration of the solid from the suspension of the liquid. Now, let us talk about the mass transfer. The mass transfer is net movement of component in a mixture from one location to another location in the presence of a difference in the concentration or a partial pressure because some driving force must be there. One example is that lump of a sugar added to a cup of water, which dissolves and then diffuses throughout the cup uniformly. Another example is to deliberate the use of agarbathi.

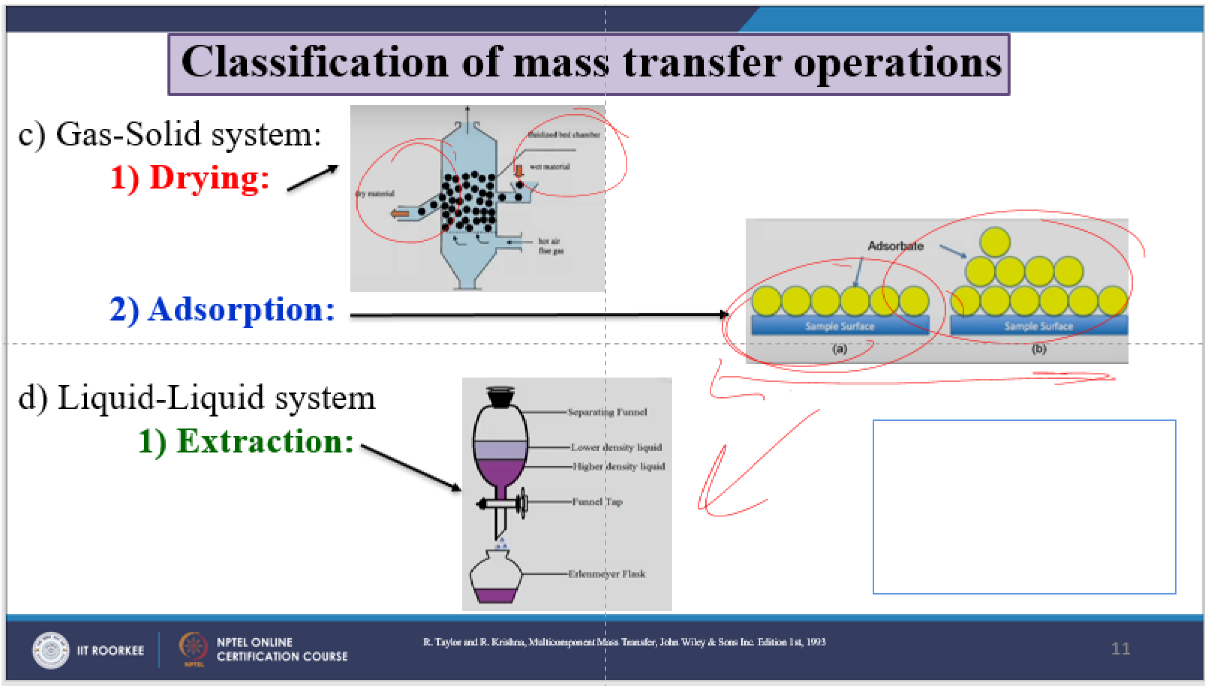


The fragments generally spread uniformly and when we put agarbathi at home. So, if you light the agarbathi at one corner over the period of time, the perfume or a fragrance it approaches to the all corners and you may say that all these fragrances distributed throughout the area in question. And drying of cloths under the sun, the drying occurs because the moisture diffuses into the air. So, these are the some of the driving forces. Then let us classify the mass transfer operation.



As we know that the three stages of matter gas, liquid and solid. So, the combination of these three states can form three different phases of possibilities of phase of contact. One is the gas-gas system, the two different gases, gas 1 and gas 2. Two different gases if we keep them in two container and allow them to mix, they will uniformly mix by the process of diffusion. Then the gas liquid type of a system, absorption.





Usually, it is one of the such examples like here you are having the gas, liquid and sparger, when the sparger is there. So, one of such example of a gas-liquid system, is suppose a solute is changing from a gas phase to the liquid phase and two mixtures of ammonia and air. Let us say that ammonia and air. We have water in the liquid phase. So, ammonia will dissolve, this is ammonia, ammonia will dissolve in water and form the ammonium hydroxide and air does not dissolve in the liquid.

So, in this case, there is an interface between the gas and liquid, and one component of the gas phase is preferentially dissolved in the liquid phase from the solution, this is known as the absorption process. Another thing is the distillation. Now here, the salient feature like you are introducing the feed over here, this is the reflexes and this is the reboiler section. And so, we have a reboiler here, where we heat the liquid and it forms a vapor phase, and its liquid is fed from the top as a reflex and it comes down like this and there is an intimate contact of between the gas and liquid. So, when there is a difference in their boiling point among the mixture or the component and we can create two phases, the vapor phase and another liquid phase, and vapour phase will be mostly on the lighter component and the liquid phase will be on the heavier component.

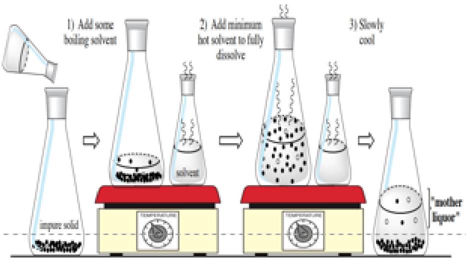
Therefore, we can separate the two different components or multiple component and this process is known as distillation. Another segment is called a drying. This is a type of a gas solid system. Now, here this is a typical dryer and you see the dry material, this is a fluidized by stitch chamber. So, some sort of a drying force is there, then adsorption is a very common phenomena over the surface.

Classification of mass transfer operations

e) Liquid-Solid system

1) **Crystallization:** the process of **formation of solids from a liquid solution** based on difference in **solute concentration** and its solubility at a certain temperature.
2) **Leaching: selective dissolution of a component from a solid particle** by a liquid solvent is known as **the leaching process**.

Example: formation of some medicinal components from the plants.



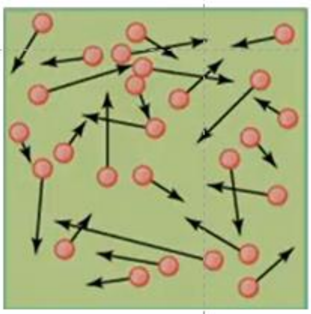
IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE | R. Taylor and R. Krishna, Multicomponent Mass Transfer, John Wiley & Sons Inc. Edition 1st, 1993 | 12

This is a sample surface over this, the adsorbate is being accumulated over the period of time. Then the liquid-liquid system, the prominent segment is the extraction. So, when we talk about the liquid-liquid system, the crystallization, the process of formation of the solid from the liquid solution based on the difference in the solute concentration and its solubility at a certain temperature. Then the leaching, this is a selective dissolution of a component from a solid particle by a liquid solvent, this is known as leaching. The example is the formation of some medicinal component from the plants.

Mechanism of mass transfer operations

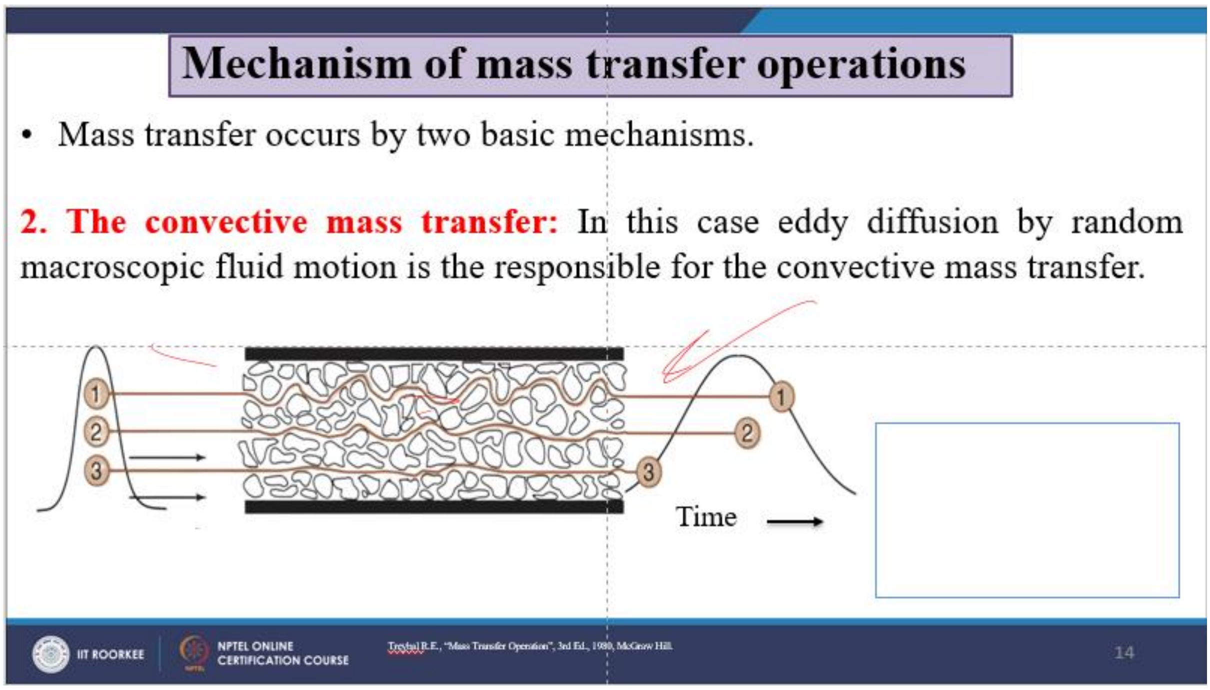
- Mass transfer occurs by two basic mechanisms.

1. **Molecular mass transfer:** The molecular diffusion by random and spontaneous microscopic movement of individual molecules in a gas, liquid or solid as a result of thermal motion is known as the molecular mass transfer.

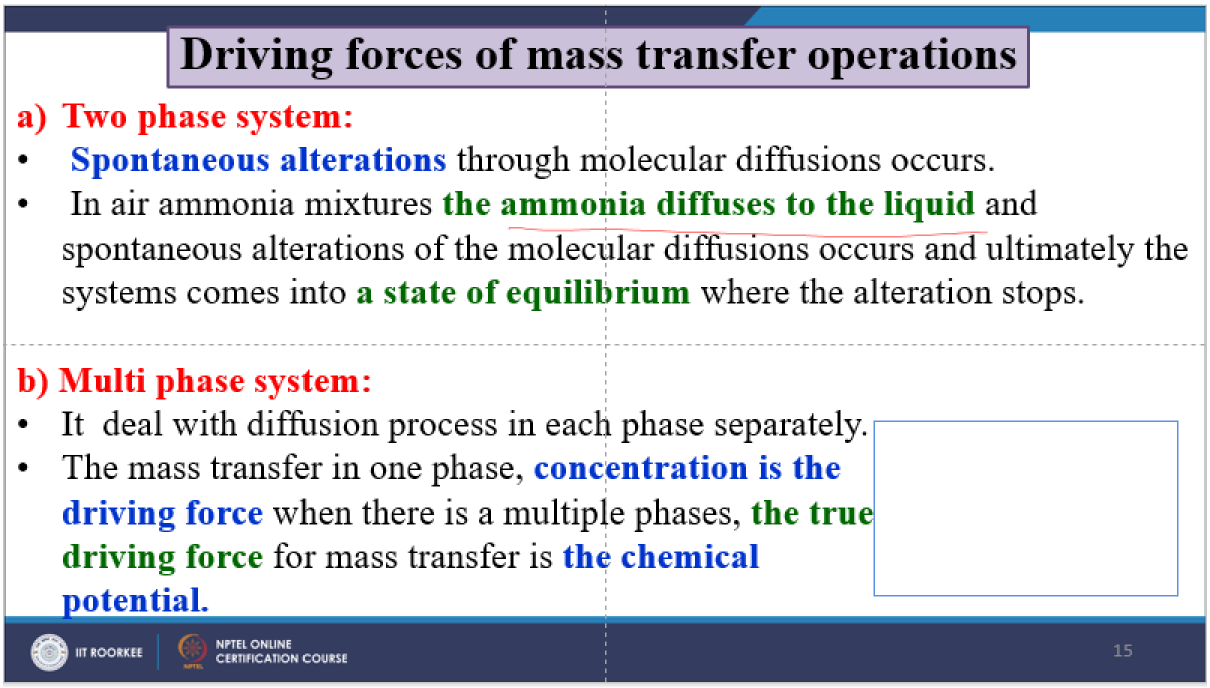


IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE | Treybal R.E., "Mass Transfer Operation", 3rd Ed., 1980, McGraw Hill | 13

Now, usually when we talk about the mechanism of mass transfer operation, so usually it occurs by two basic mechanisms. One is the molecular mass transfer, the molecular diffusion by random and spontaneous microscopic movement of individual molecule in a gas, liquid or a solid as a result of a thermal motion which is known as the molecular mass transfer. Then the convective mass transfer, in this case the ED diffusion by the random macroscopic fluid motion is the responsible function for the convective mass transfer. Here you see that. What are the driving force for mass transfer operation? You see when we, the agarbati at one corner and it goes to the other part, then there must be some driving force.

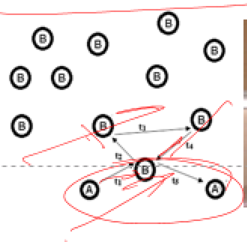


So, let us talk about those driving force for this mass transfer operation. One is the two-phase system, the spontaneous alteration through the molecular diffusion occurs in air ammonia mixture. The ammonia diffuses to the liquid and spontaneous alteration of the molecular diffusion occurs and ultimately the system comes into a state of equilibrium where the alteration stops. Another is the multi-phase system. It deals with diffusion process in each phase separately and the mass transfer in one phase, the concentration is the driving force where there is a multiple phase, the two-driving force for the mass transfer is the chemical potential.



Molecular Diffusion

- **The molecular diffusion** is defined by **the movement of individual molecules** through a substance by virtue of **their thermal energy.**
- This can be explained **by simplified kinetic theory.**
- Consider two different types of molecules: molecule A and molecule B.
- **A molecule is imagined to travel in a straight path** at a uniform velocity until it **collides** with another molecules, whereupon **its velocity changes** both in their direction as well as magnitudes.



Let us talk about the molecular diffusion. The molecular diffusion is defined by the movement of individual molecules through the substance by virtue of their thermal energy. Now this can be explained by the simple kinetic theory. Now consider the two different type of molecules, molecule A and molecule B. A molecule is imagined to travel in a straight path at a uniform velocity until it collides with another molecule where upon its velocity change and both the directions as well as the magnitude.

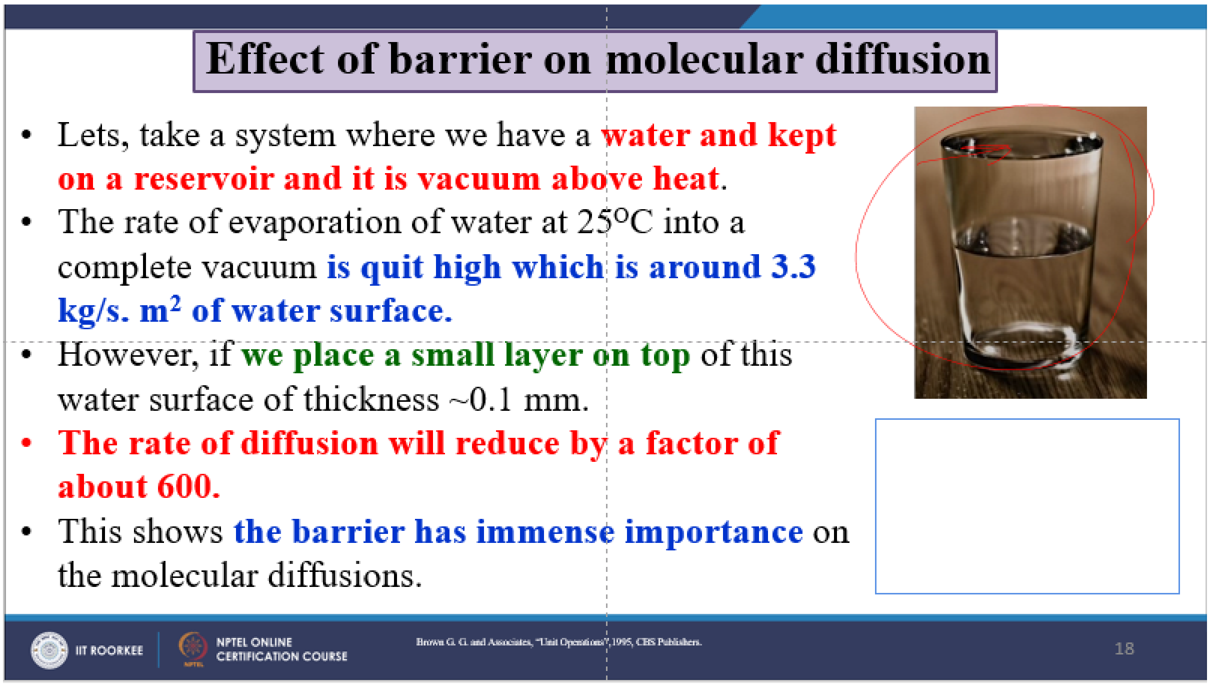
Mean free-path

- **The net distance** or the average distance **the molecules travels** between the two collisions is known as **the mean free path.**
- The molecules travels through a **highly zigzag path**.
- **The net distance travel in one direction** in a given time is defines as **the rate of diffusion.**
- The rate of molecular diffusions is **very slow**.
- The rate of diffusion can be:

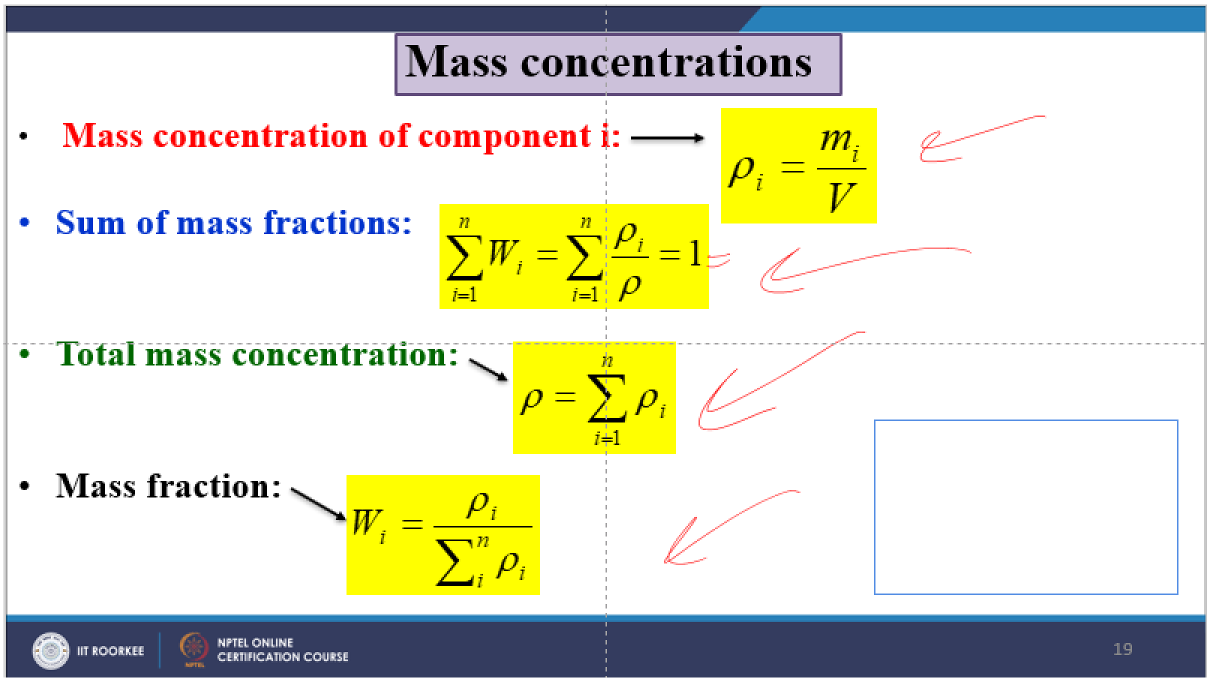
a) **Increased by reducing the pressure:** reduces the number of collisions.

b) **Increased by increasing temperature:** increase the molecular velocity.

So, this is A and it collides with B. Now the net distance of or the average distance of the molecule travel between the two collision is known as the mean free path here. The molecule travels through a highly zigzag path. The net distance travel in one direction in a given time is defined as the rate of a diffusion. So, the rate of molecular diffusion is very slow and this the rate of diffusion can be increased by reducing the pressure.



When we reduce the pressure, then this reduces the number of collision and increasing by this can be increased by the increasing temperature. When this increases the molecular velocity. Now let us talk about the effect of barrier on the molecular diffusion. Let us take a system where we have a water and, on a reservoir, and it is vacuum above heat. So, the rate of evaporation of water at say 25 degree Celsius into the complete vacuum is quite high which is around 3. 3 kilograms per centimeter per square meter of water surface. Now if we place a small layer on top of this water surface of thickness say 0.1 mm, the rate of diffusion will reduce by a factor of say about 600. This shows the barrier has an immense importance on the molecular diffusion. Let us talk about the mass concentration.

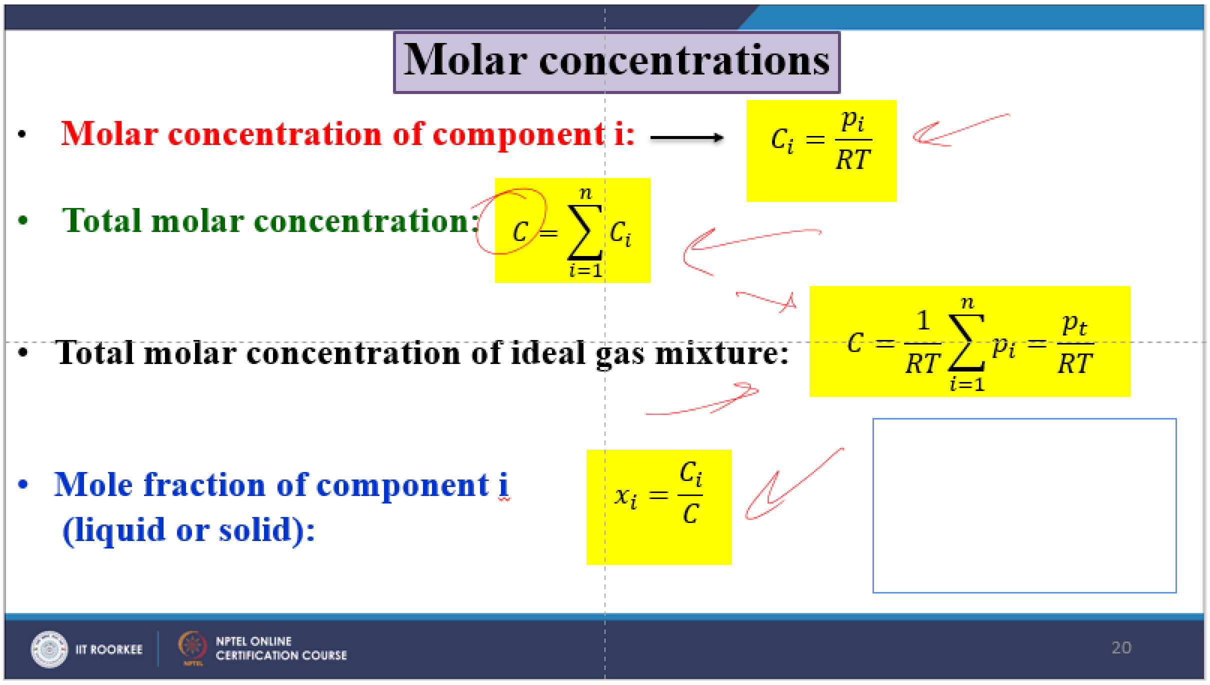


$$\rho_i = \frac{m_i}{V}$$

$$\sum_{i=1}^{n} W_i = \sum_{i=1}^{n} \frac{\rho_i}{\rho} = 1$$

$$\rho = \sum_{i=1}^{n} \rho_i$$

$$W_i = \frac{\rho_i}{\sum_i^n \rho_i}$$



$$C_i = \frac{p_i}{RT}$$

$$C = \sum_{i=1}^{n} C_i$$

$$C = \frac{1}{RT}\sum_{i=1}^{n} p_i = \frac{p_t}{RT}$$

$$x_i = \frac{C_i}{C}$$

Mole fraction component I (in ideal gas mixture)

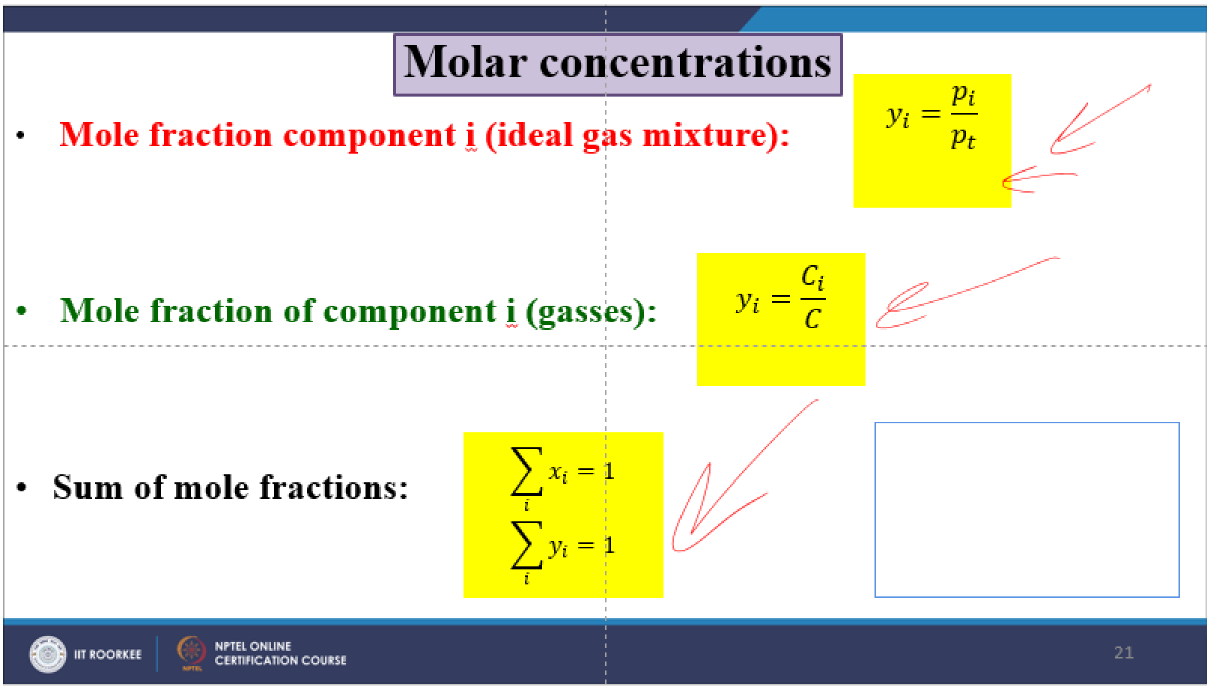
$$y_i = \frac{p_i}{p_t}$$

Mole fraction of component I (in gasses)

$$y_i = \frac{C_i}{C}$$

Sum of mole fractions

$$\sum_i x_i = 1 \sum_i y_i = 1$$



The mass concentration of the component is given by the rho i is equal to m i over v and some of the mass fractions can be given as summation of i is equal to 1 to n w i. This can be the summation of i to n rho i over rho that must be equal to 1 and the total mass concentration can be given as rho is equal to summation of i to n rho i and the mass fraction is w i is equal to rho i over summation of i to n rho i. Another component in question is that molar concentration of component i that is c i is equal to p i over r t and the total molar concentration can be given represented as c is equal to summation of i to n c i and the total molar concentration of ideal gas mixture can be given or can be mathematically represented by this particular formula c is equal to 1 over r t summation of i to n p i is equal to p t over r t and the mole fraction of component i that is very common in the liquid or solid that can be given as x i is equal to c i over c and the mole fraction of component i in the ideal gas mixture this can be given as y i is equal to p i over p t that is the total pressure and the mole fraction of the component i in gases can be given in terms of the concentration and that is y i is equal to c i over c. So, if we talk about the sum of the mole fraction that is the summation i is equal to x i is equal to 1 and y i summation y i is equal to 1.

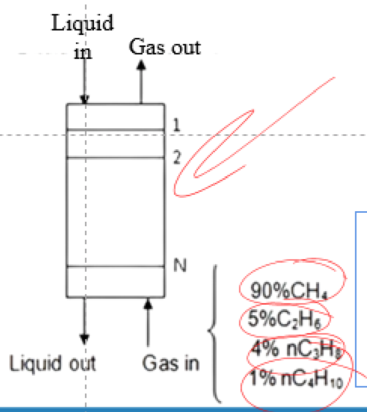
Question-1

Question: **The feed gas** to an absorber **has the following composition at 313 K and 200 kPa** as given in the figure:

Calculate:

a) **the composition of the feed gas in terms of the mass fraction.**

b) **total concentration in the feed gas.**



Foust A. S., Wenzel L. A., Clump C. W., Maus L. and Andersen L.B., "Principles of Unit Operations", 2nd Ed., 2008, Wiley-India

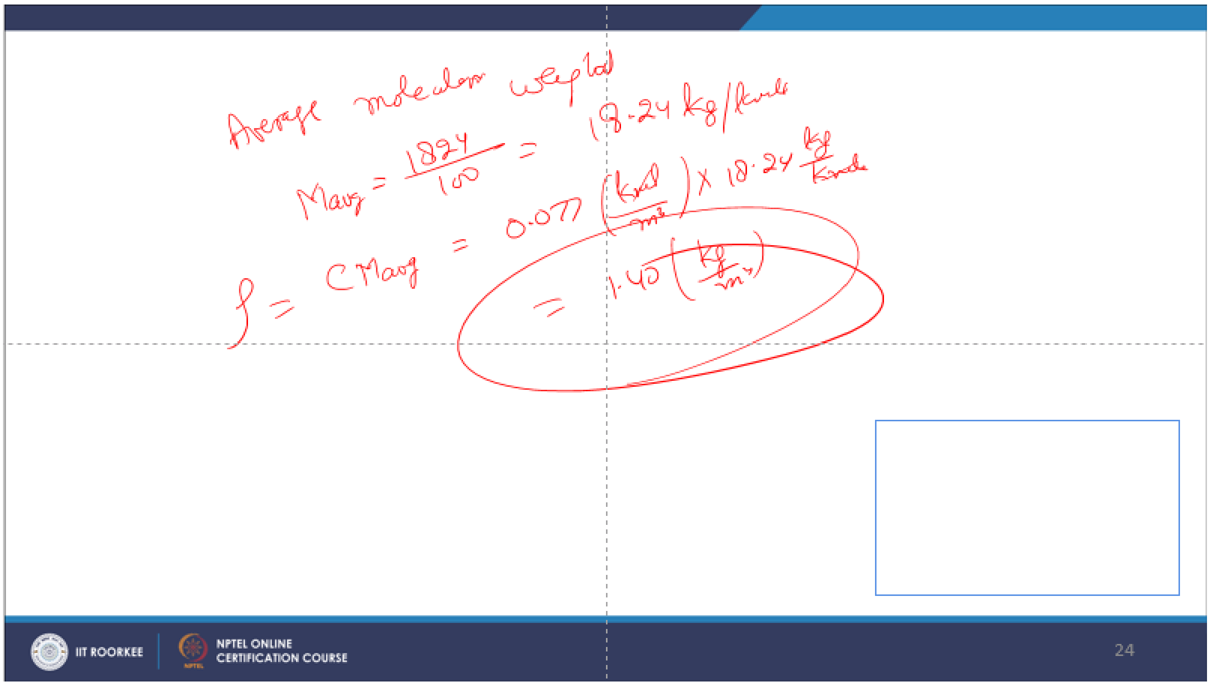
Now, let us take up one question that is the feed to an absorber has the following composition at 313 Kelvin and 200 kilopascal that is per the given the figure like 90 percent of methane then 5 percent c 2 h 6 4 percent of n c 3 h 8 and 1 percent of n c 4 h 10 and you need to calculate the composition of the feed gas in terms of the mass fraction and the total concentration in the feed gas.

Basis 100 kmol of feed gas mixture

total molar concentration c

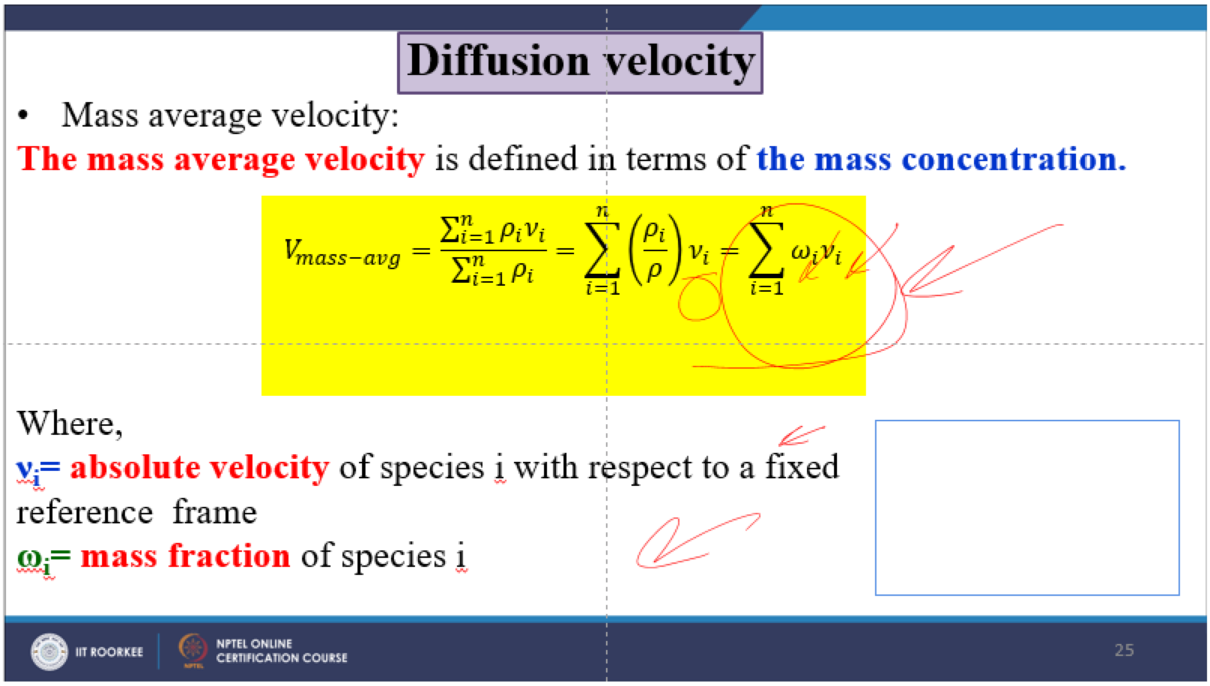
$$C = \frac{P_t}{RT} = \frac{200}{8.314 \times 313} = 0.077 \text{ kmol/m}^3$$

Components	kmol	Mol. Wt.	Mass (kg) = kmol x Mol wt.	Mass fractions
CH_4	90	16	1440	0.80
C_2H_6	5	30	150	0.08
nC_3H_8	4	44	176	0.09
nC_4H_{10}	1	58	58	0.03
Total	100		1824	1.0



Now, for this we need to take the basis 100 kilo mole of feed gas mixture. Now, here we have given the components c h 4 c 2 h 6 and c 3 h 8 butane and which is total 100 and the mole molecular weight and the mass in kilogram or kilo mole the molecular weight and the mass fraction is given like this because we have calculated the total one. So, the molar concentration total molar concentration c the c is equal to p i over r t and this 200 is given 8.314 into 313 and that comes out to be 0.

077 kilo mole per meter cube. So, average molecular weight m average is equal to 1824 over 100 and that comes out to be 18.24 kilogram per kilo mole. So, the total mass concentration rho is given by c m average which is 0.077 kilo mole per meter cube into 1824 kilogram per kilo mole. This comes out to be 1.40 in per meter cube and this is our answer. Now, let us talk about the diffusion and velocity.

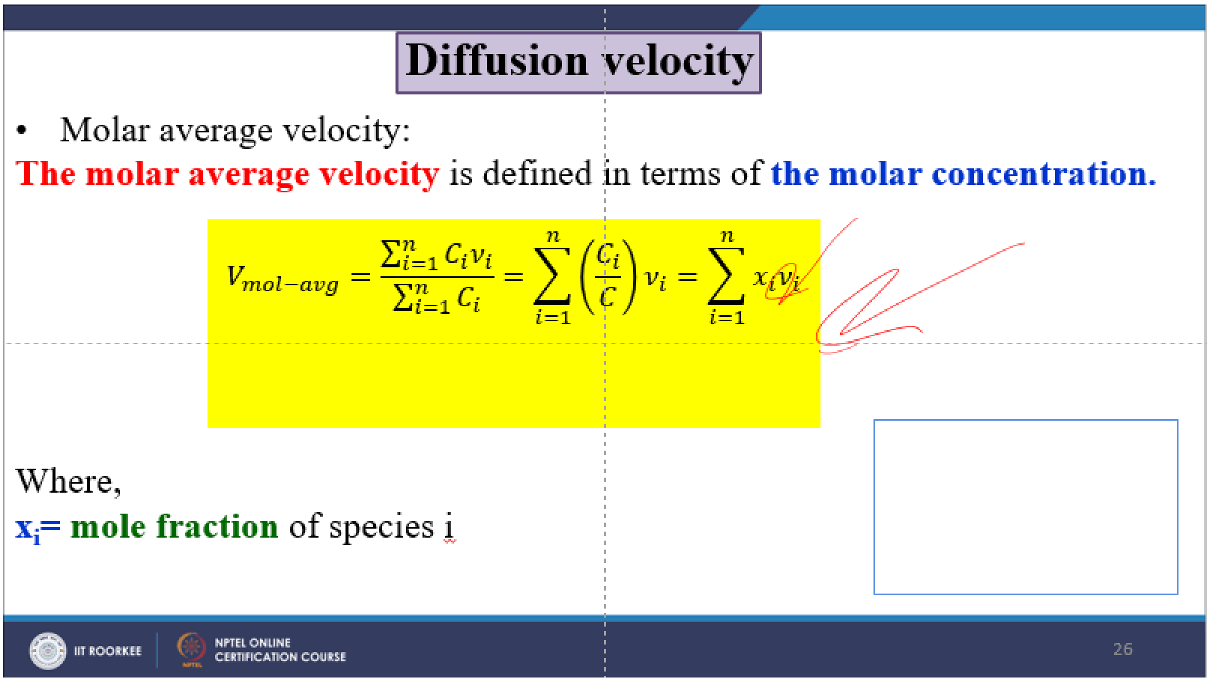


$$V_{mass-avg} = \frac{\sum_{i=1}^{n} \rho_i v_i}{\sum_{i=1}^{n} \rho_i} = \sum_{i=1}^{n} \left(\frac{\rho_i}{\rho}\right) v_i = \sum_{i=1}^{n} \omega_i v_i$$

Where,

v_i= absolute velocity of species i with respect to a fixed reference frame

ω_i= mass fraction of species i



The molar average velocity is defined in terms of the molar concentration;

$$V_{mol-avg} = \frac{\sum_{i=1}^{n} C_i v_i}{\sum_{i=1}^{n} C_i} = \sum_{i=1}^{n} \left(\frac{C_i}{C}\right) v_i = \sum_{i=1}^{n} x_i v_i$$

The mass average velocity is defined as the mass concentration which can be represented as this particular mathematical relationship where v v v i is equal to absolute velocity of a species i with respect to a fixed reference frame and omega 1 omega i is equal to mass fraction of a species i. So, this is the v mass average is summation of i to n rho i v i over summation p rho i and that is equal to summation i to n rho i over rho into v i and this is the summation i is i is equal to 1 to n omega i into v i. If we talk about the diffusion velocity, then the molar average velocity is very important and it is sometimes defined as in terms of a molar concentration. So, which can be represented like this where x i this is slightly different from the previous formula here x i is the mole fraction of a species i rather here we use this omega i which is a mass fraction of a species i.

Question-2

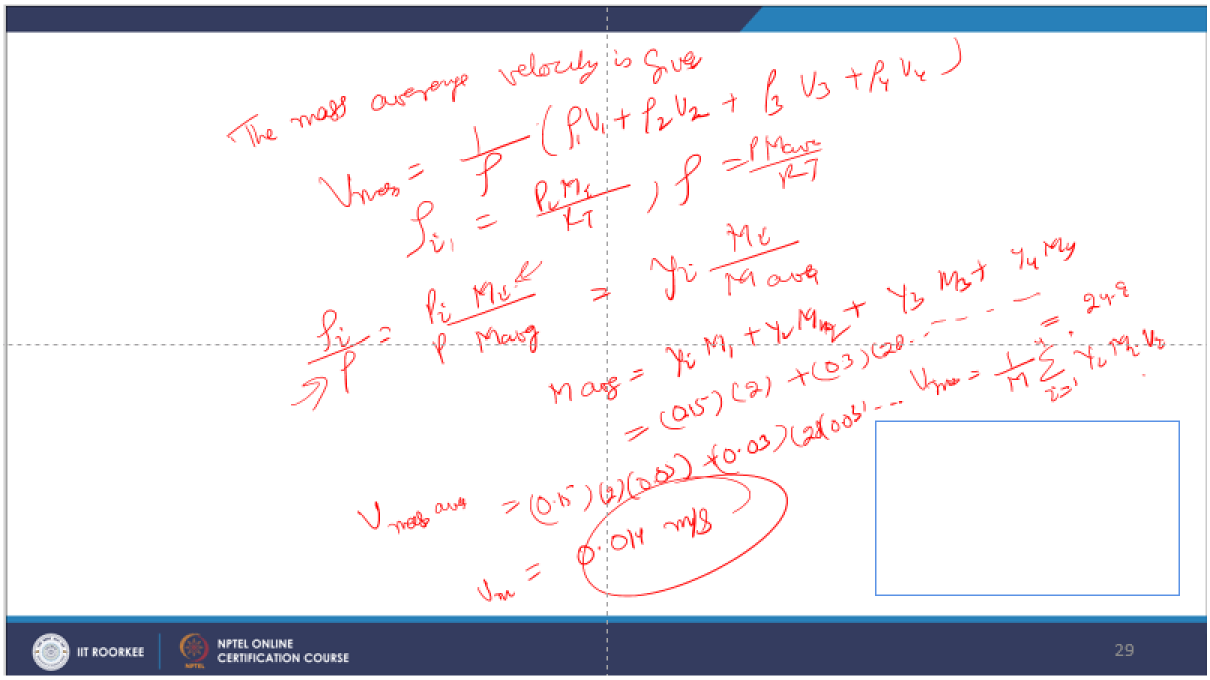
Question: A gas mixture containing **H_2: 15 %, CO: 30 %, CO_2: 5 % and N_2: 50 %** flows through a tube of **1 inch diameter, at 15 bar total pressure**. If the velocities of the respective components are 0.05 m/s, 0.03 m/s, 0.02 m/s and 0.03 m/s. **Calculate the mass average and molar average velocities of the mixture?**

Now, let us take up another question that is a gas mixture this contains about 15 percent of hydrogen, 30 percent of carbon monoxide and 5 percent of CO2 and remaining is nitrogen. This flow through a tube of say 1 inch diameter and 15 bar with the total pressure. If the velocities of the respective component they are 0.

$H_2 \Rightarrow 1 \quad CO \Rightarrow 2 \quad CO_2 \Rightarrow 3 \quad N_2 \Rightarrow 4$

$$V_{molar} = \frac{1}{C}(C_1V_1 + C_2V_2 + C_3V_3 + C_4V_4) = y_1V_1 + y_2V_2 + y_3V_3 + y_4V_4$$

$$V_{molar} = (0.15)(0.05) + (0.3)(0.03) + (0.05)(0.02) + (0.5)(0.03) = 0.0325 \text{ m/s}$$



05 meter per second and 0.03 meter per second and 0.02 meter per second respectively, you need to calculate the mass average and molar average velocities of the mixture. Now, let us rename the gas mixture as H2 is equal to H21CO2CO23 and N24. So, the molar average velocities can be given as per the formula 1 over C, C1V1 plus C2V2 plus C3V3 plus C4V4 and thus that comes out to be Y1V1 plus Y2V2 plus Y3V3 plus Y4V4 where Y is the mole fraction of component i in the gas mixture. So, if we put the values then V can be given as 0.

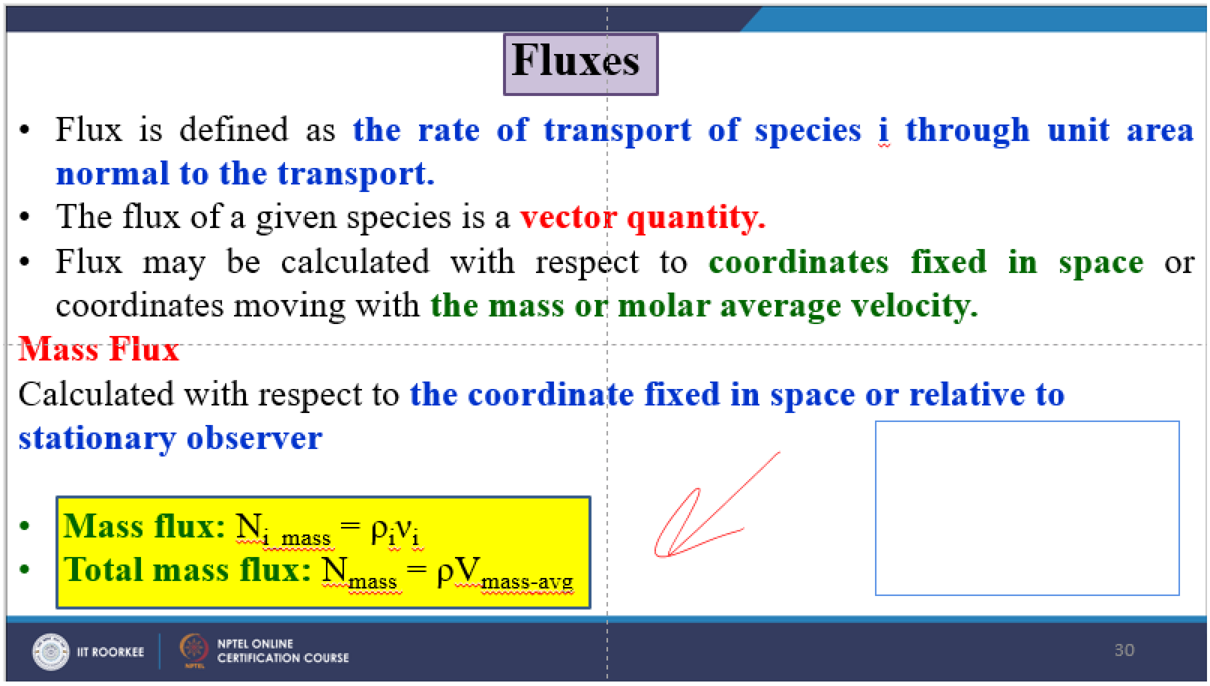
15 into 0.05 plus 0.3 into 0.03 plus 0.05 into 0.02 plus 0.5 into 0.03 and this comes out to be the 0.

0325 meter per second. So, the mass average velocity the mass average velocity is given by V mass average which is equal to rho into rho 1 V1 plus rho 2 V2 plus rho 3 V3 plus rho 4 V4 and rho i is equal to Pi Mi over RT and rho is equal to P m average over RT. So, rho i over rho is equal to Pi Mi over P m average which is equal to Yi Mi over m average where rho i is the mass density of ith component, rho is the total mass density, Mi is the molecular weight of ith component and m average is the average molecular weight of the mixture. Now, if we put all the values, so, m average is equal to Yi m1 plus Y2 m2 plus Y3 m3 plus Y4 m4 and if we substitute the value 0.15 into 2 plus 0.

3 into 28 and so on, this comes out to be 24.9. So, if we calculate V mass average that is 1 over 1 1 over m that is summation of i is equal to 1 to n is equal to 4 because and Yi Mi Vi. So, if we substitute the value of V mass average which is comes out to be if we substitute all the values given, then it comes out to be 0. 15 into 2, 0.505 plus 0.03 into 28 into 0.03 and so on. This comes out to be V m mass average comes out to be 0.14 metre per second and that is our answer.

Mass flux: $N_{i\_mass} = \rho_i v_i$

Total mass flux: $N_{mass} = \rho V_{mass\text{-}avg}$



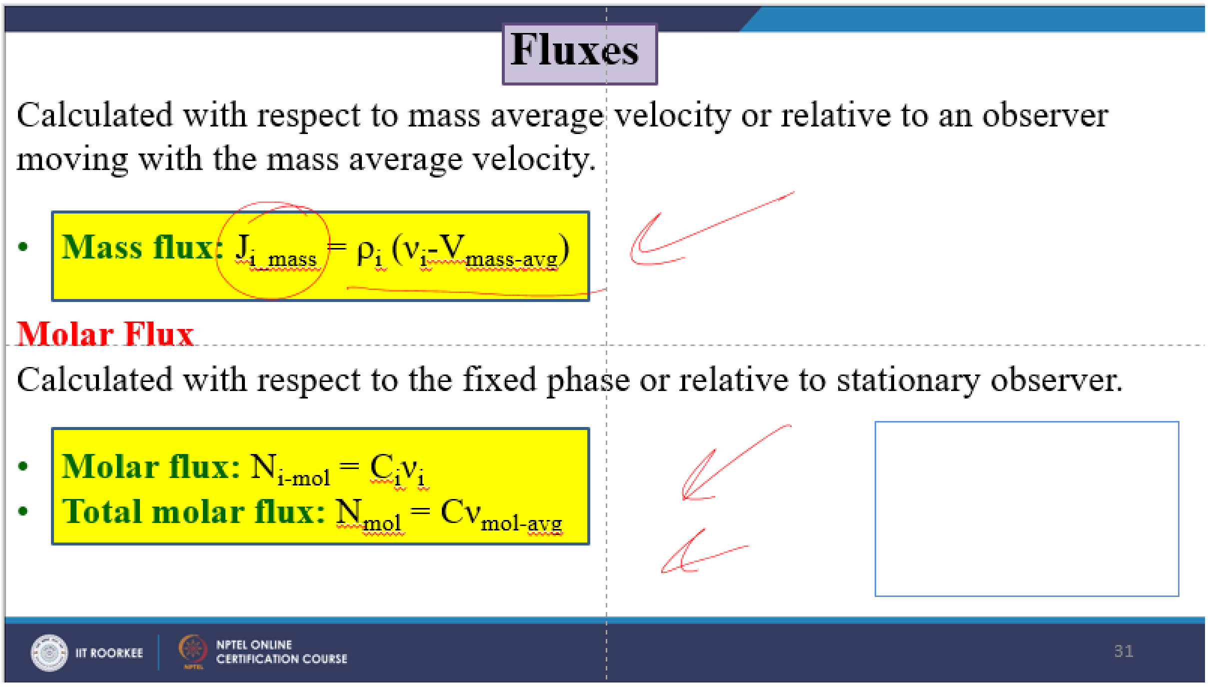
Let us talk about the fluxes. Now, flux is defined as the rate of transport of a species i through the unit area normal to the transport. Now, the flux of a given species is a vector quantity. Flux may be calculated with respect to the coordinates fixed in space or coordinates moving with mass or molar average velocity. Now, mass flux, this is calculated with respect to the coordinate fixed in space or relative to the stationary observer.

Mass flux: $J_{i\_mass} = \rho_i (v_i - V_{mass\text{-}avg})$

Molar flux: $N_{i\text{-}mol} = C_i v_i$

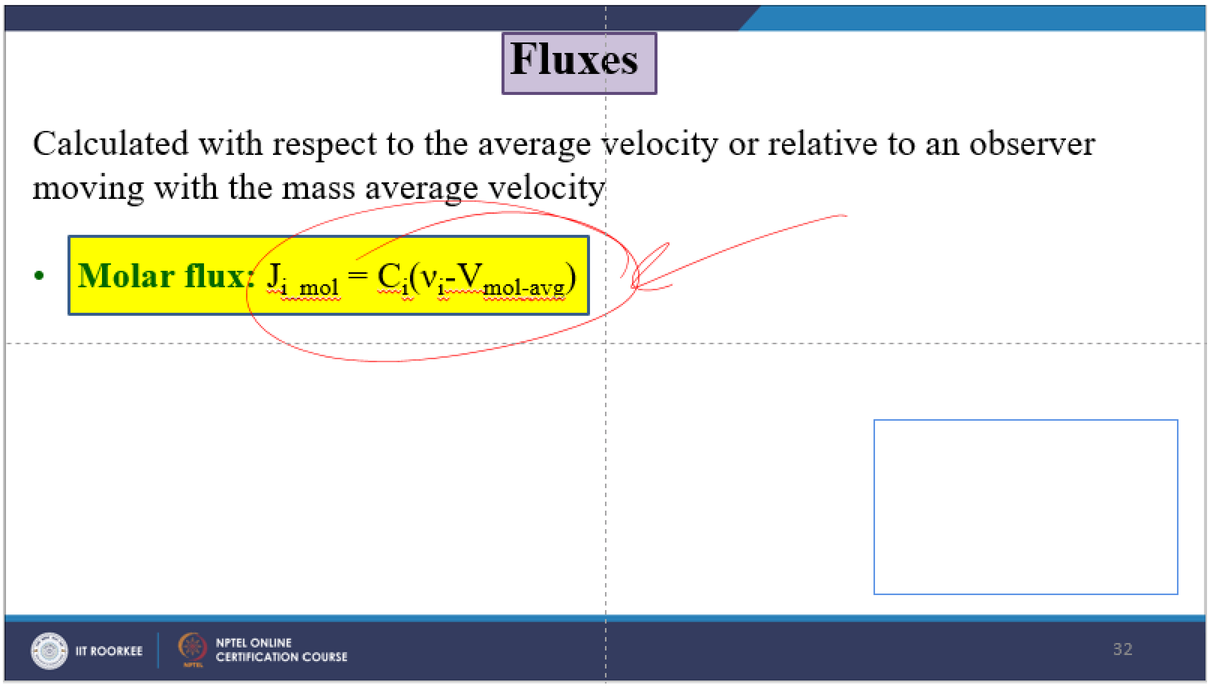
Total molar flux: $N_{mol} = C v_{mol\text{-}avg}$

Molar flux: $J_{i\_mol} = C_i(v_i - V_{mol\text{-}avg})$

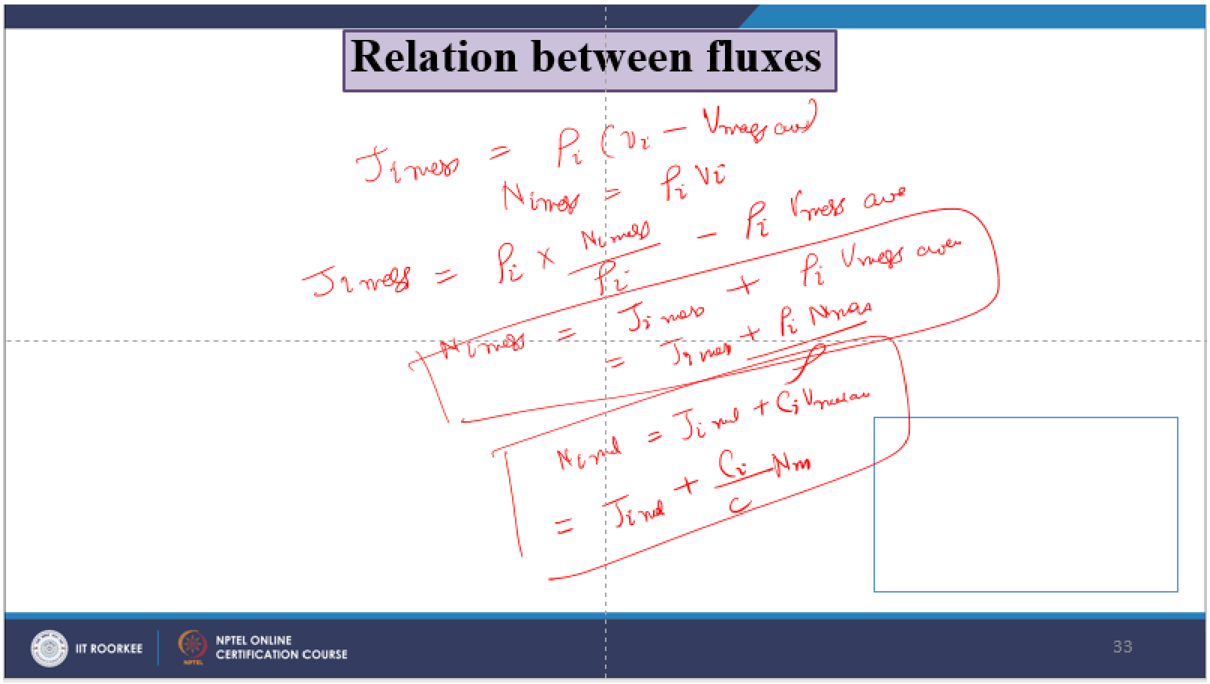


So, this can be represented by this formula that is the mass flux Ni mass is equal to rho i into Vi the total mass flux and mass is equal to rho V mass average. Now, the calculated with respect to the mass average velocity or relative to an observer moving with the mass average velocity and thus can be the mass plus that is J i mass is equal to rho i into Vi minus V mass average and the molar flux, this is calculated with respect to the fixed phase or relative to stationary observer.

So, the molar flux is equal to N molar that is Ci Vi then total molar flux that is N mole is equal to C V molar average. Now, this calculated with respect to the average velocity or the relative to an observer moving with the mass average velocity.



So, the molar flux J i, this can be represented at Ci Vi minus V mole average. Now, let us talk about the relations between the fluxes. So, this can be J i mass is equal to rho i Vi minus V mass average and Ni mass is equal to rho i Vi and J i mass is equal to rho i into Ni mass over rho i minus rho i V mass average.



So, the Ni mass is equal to J i mass plus rho i V mass average and this comes out to be J i mass plus rho i N mass over rho. So, this is my first formula. Similarly, we can write Ni mole is equal to J i mole plus C i V mole average and this comes out to be J i th component plus C i over C N mole. So, this is our next one. Now, let us talk about the Fick's law of molecular diffusion.

For diffusion of component A in x direction is

$$J_{A,x} = -D_{AB}\frac{dC_A}{dx}$$

Where,

$J_{A,x}$ = molar flux of component A in x-direction

Unit: amount of material diffused/$(l)^2(t)$

D_{AB} = the diffusion coefficient

Unit: l^2/t

C_A= Concentration of A

Fick's law of molecular diffusion

- **Adolf Eugen Fick** a German physiologist he has given a law for the diffusion of components.
- The Fick's first law defines **the diffusion flux of a component A** in an isothermal, isoberic binary system is **proportional to the concentration gradient** in a particular direction.

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Unit: l^2/t

C_A= Concentration of A

Now, Fick, the head of Eugene Fick's, a German physiologist, he has given a law for the diffusion of a component. The Fick's first law defines the diffusion flux of a component A in an isothermal, isobaric binary system and proportional to the concentration gradient in a particular direction. For diffusion of a component A in X direction is given by J Ax is equal to minus D AB dCA over dX where J A, this is the molar flux of component A in X direction, the unit is having the amount of material diffused over N square time and then this D AB is the diffusion coefficient and CA is the concentration of A. Now, the relationship between the mutual diffusivity of species A and B, this can be given by say N A is equal to J A plus CA over C N. This is equation number 1 and for gas mixture CA over C is equal to Y A and J A can be represented as minus D AB dCA over dX.

Relationship between mutual diffusivity of species A and B

$$N_A = J_A + \frac{C_A}{C} N \quad \text{---} (1)$$

$$\frac{C_A}{C} = y_A \quad \& \quad J_A = -D_A \frac{dC_A}{dx}$$

$$N_A = -D_{AB}\frac{dC_A}{dx} + y_A N \quad \text{---} (2)$$

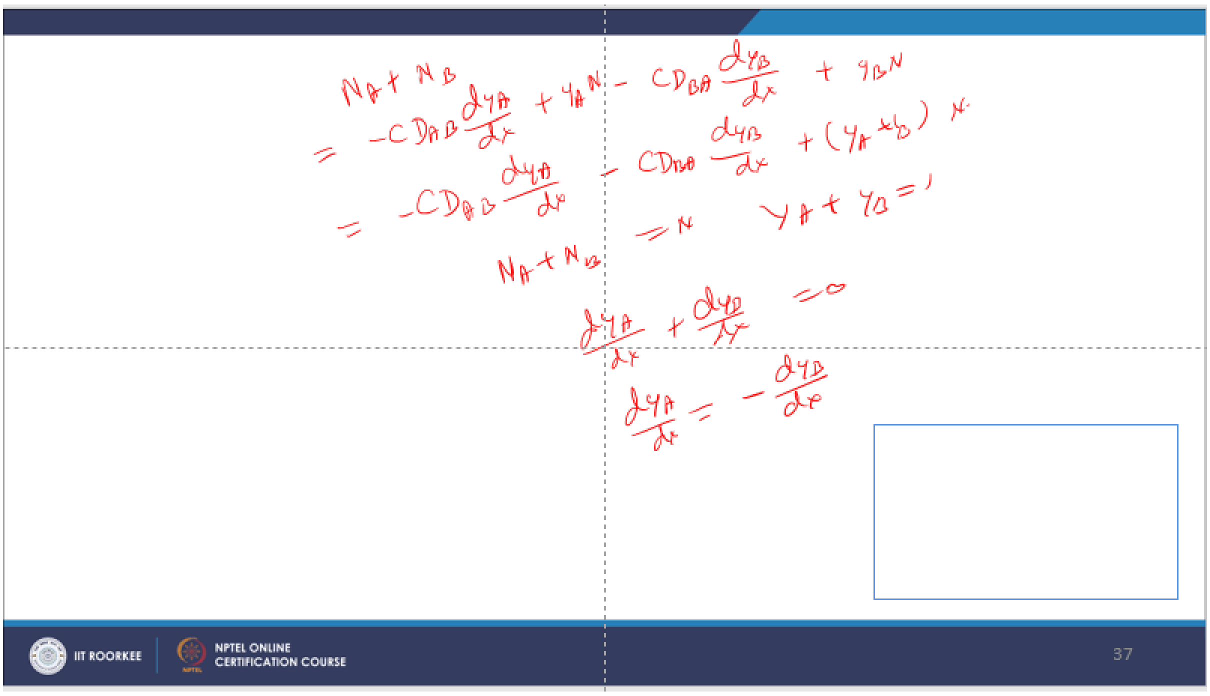
$$\frac{dC_A}{dx} = C\frac{dy_A}{dx}$$

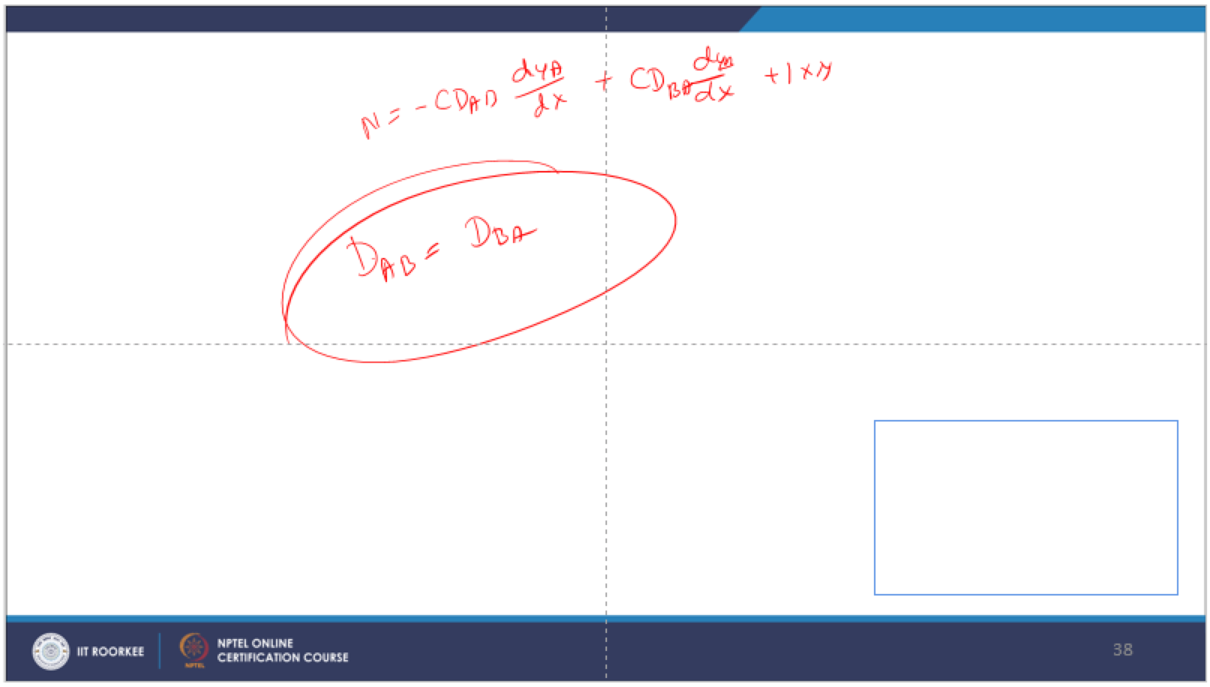
$$N_A = -CD_{AB}\frac{dy_A}{dx} + y_A N \quad \text{---} (3)$$

$$N_B = -CD_{BA}\frac{dy_B}{dx} + y_B N \quad \text{---} (4)$$

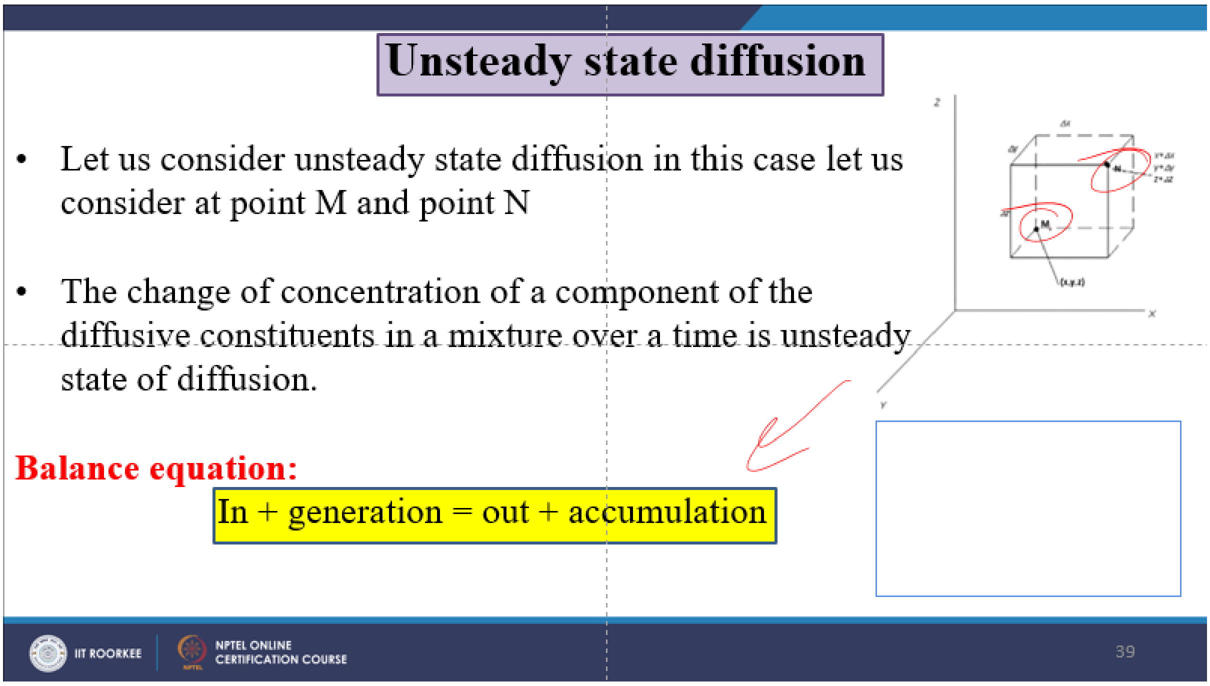
So, if we put the values in the equation 1, we get N A is equal to minus D AB dCA over dX plus Y A N. This is our equation 2. Also, dCA over dX is equal to C dY A over dX. So, therefore, the equation 2 becomes, this equation can become N A is equal to minus C D AB dY A over dX plus Y A N.

This is our equation number 3. Similarly, N B is equal to minus C D A dY B over dX plus Y B N. This is equation number 4. Now, some if we sum these two, equation 3 and 4, we get N A plus N B that is comes out to be minus C D AB dY A over dX plus Y A N minus C D B A dY B over dX plus Y B N or minus C D AB dY A dX minus C D B A dY B over dX plus Y A plus Y B N. Now, since for two components, N A plus N B is equal to N, Y A plus Y B is equal to 1. So, dY A over dX plus dY B over dX is equal to 0 and dY A over dX is equal to minus dY B over dX.





Therefore, N is equal to minus C D AB dY A over dX plus C D B A dY B over dX plus 1 into N. Hence, d AB is equal to dBA. Now, let us talk about the unsteady state diffusion. So, let us consider unsteady state diffusion in this particular case.



Mass flow rate of component A in

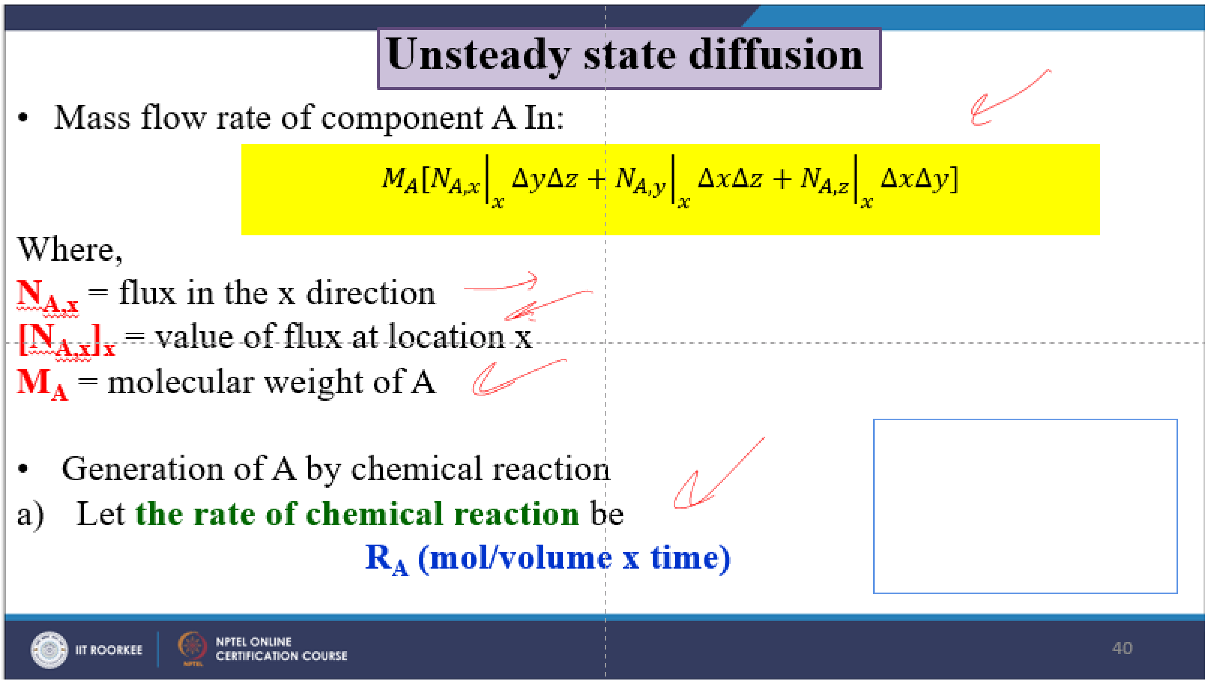
$$M_A[N_{A,x}|_x \Delta y \Delta z + N_{A,y}|_x \Delta x \Delta z + N_{A,z}|_x \Delta x \Delta y]$$

Where,

$N_{A,x}$ = flux in the x direction

$[N_{A,x}]_x$ = value of flux at location x

M_A = molecular weight of A



Let us have a consider the point M here and a point N. The change in the concentration of a component of the diffusive constituent in a mixture over a time is unsteady state diffusion and the balance equation can be given as L N generation is equal to out plus accumulation. So, the mass flow rate of the component A can be given this particular equation where N A X is the flux in the X direction and this one is the value value of the flux at location some location X and M A is the molecular weight of A. So, the generation of A by the chemical reaction. Now, let us the rate of the chemical reaction be R A is equal to mole per volume into time and the rate of generation of the product can be given by this particular mathematical representation and mass flow rate of the component A out can be represented by this and the rate of accumulation which can be represented in the data form like where rho is rho A is the density of component A. Now, suppose we put all the values in the balance equation. In that case, it can become the M A into N A X X plus delta X minus N A X delta Y delta Z plus N A Y X plus delta X minus N A Y X delta X delta Z plus N A Z X plus delta X minus N A Z X delta X delta Y plus delta X delta Y delta X del A del rho A over del t and that is equal to M A R A delta X delta Y delta Z.

Rate of generation or production

$$M_A R_A \Delta x \Delta y \Delta z$$

Mass flow rate of component A out

$$M_A[N_{A,x}|_{x+\Delta x} \Delta y \Delta z + N_{A,y}|_{x+\Delta x} \Delta x \Delta z + N_{A,z}|_{x+\Delta x} \Delta x \Delta y]$$

Rate of accumulation

$$\Delta x \Delta y \Delta z \frac{\partial \rho_A}{\partial t}$$

Where,

ρ_A is the density of component A

Unsteady state diffusion

b) Rate of generation or production: $M_A R_A \Delta x \Delta y \Delta z$

c) Mass flow rate of component A out:

$$M_A[N_{A,x}\big|_{x+\Delta x}\Delta y\Delta z + N_{A,y}\big|_{x+\Delta x}\Delta x\Delta z + N_{A,z}\big|_{x+\Delta x}\Delta x\Delta y]$$

d) Rate of accumulation: $\Delta x\Delta y\Delta z\dfrac{\partial \rho_A}{\partial t}$

Where,

ρ_A is the density of component A

Unsteady state diffusion

$$M_A[(N_{Ax}|_{x+\Delta x} - N_{Ax}|_x)\Delta y\Delta z + (N_{Ay}|_{x+\Delta x} - N_{Ay}|_x)\Delta x\Delta z + (N_{Az}|_{x+\Delta x} - N_{Az}|_x)\Delta x\Delta y] + \Delta x\Delta y\Delta z\frac{\partial \rho_A}{\partial t} = M_A R_A \Delta x\Delta y\Delta z$$

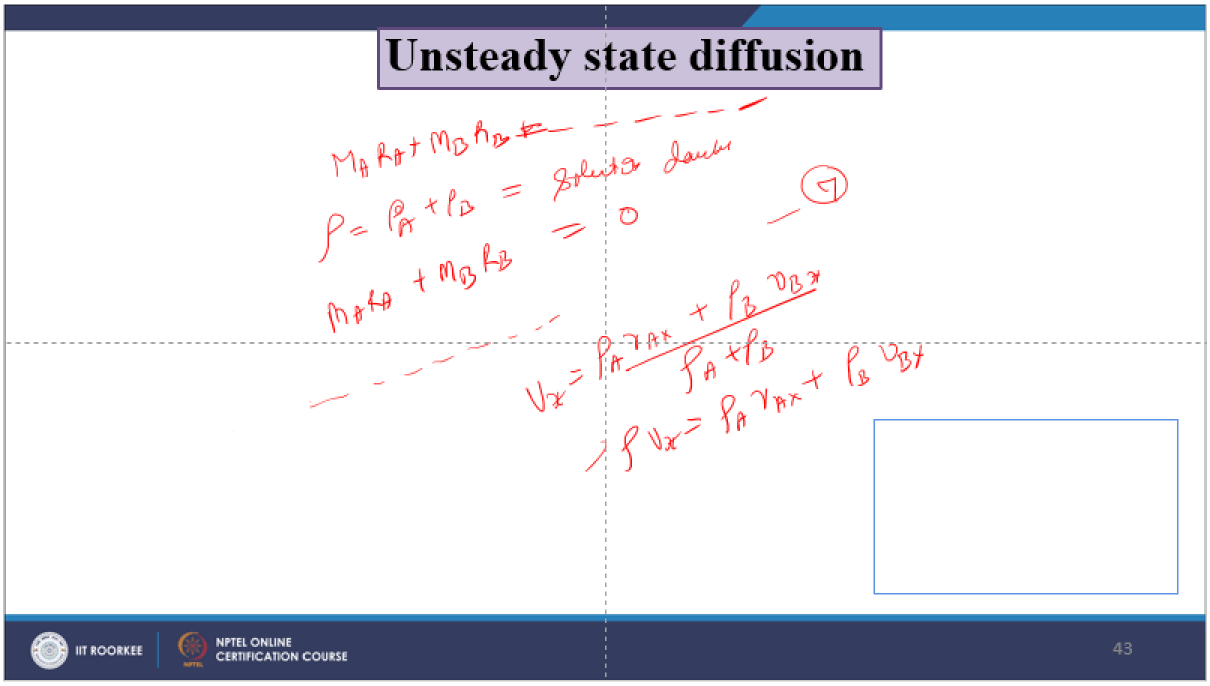
$\Delta x\Delta y\Delta z$

$\Delta x \to 0 \quad \Delta y \to 0 \quad \Delta z \to 0$ — (5)

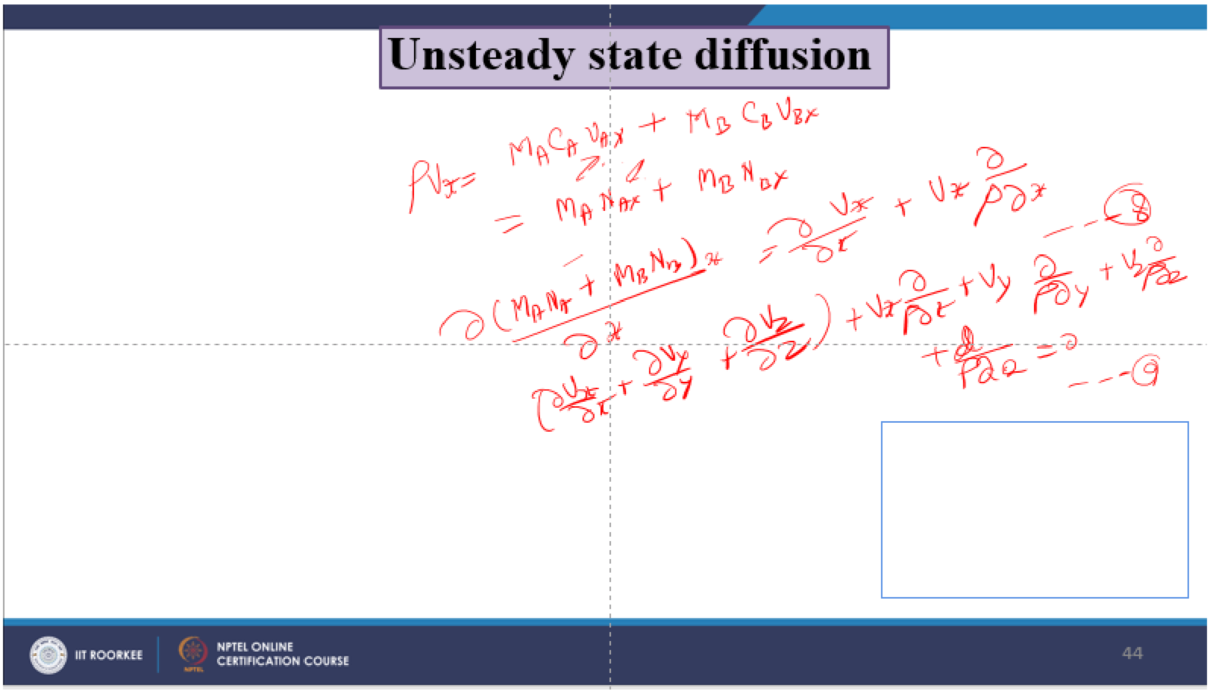
$$M_A\left(\frac{\partial N_{Ax}}{\partial x} + \dots\right) + \frac{\partial \rho_A}{\partial t} = M_A R_A$$

$$M_B\left(\frac{\partial N_{Bx}}{\partial x} + \dots\right) = M_B R_B \quad \text{— (6)}$$

Now, if you divide both the side by delta X delta Y delta Z and if you take this delta X tends to 0 delta Y tends to 0 and delta Z tends to 0. So, for we have the component for component A that is M A del N A X over del X plus and so on plus delta del over rho A over del t is equal to M A R A this can be equation number 5. And if similarly, we can write for the component B and that that can be represented as M B R B or M B del N B X over del X plus and so on. This can be equation 6. Now, the total material balance after adding equation 5 and equation 6 can be represented by M A R A plus M B R B.

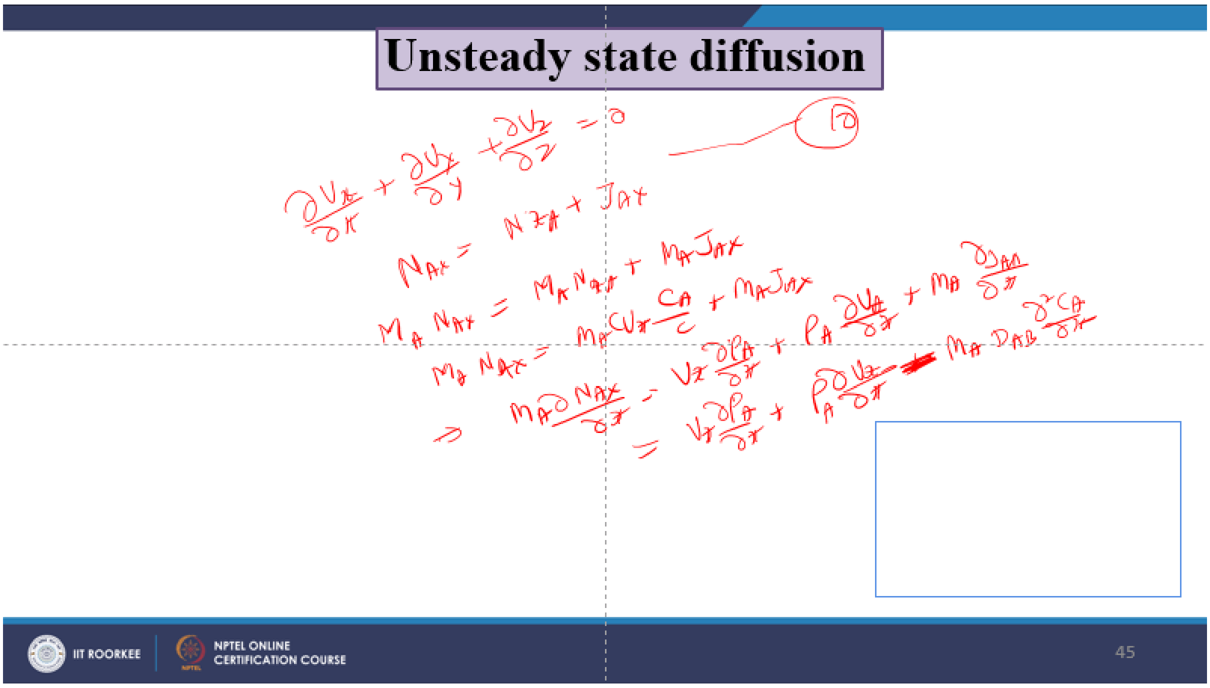


Now, if we take the rho is equal to rho A plus rho B that is the solution density in that case M A R A plus M B R B must be equal to 0. So, if we substitute to this all these things it can become the equation number 7. Since the mass rate of generation, A and B must be equal to 0. So, V X is equal to rho A V A X plus rho B V B X over rho A plus rho B or rho V X is equal to rho A V A X plus rho B V B X. So, rho V X equal to M A C A V A X plus M B C B V B X and which is equal to M A N A X plus M B N B X where V X is the mass average velocity, V A X is the absolute velocity and N A X is the molar flux.

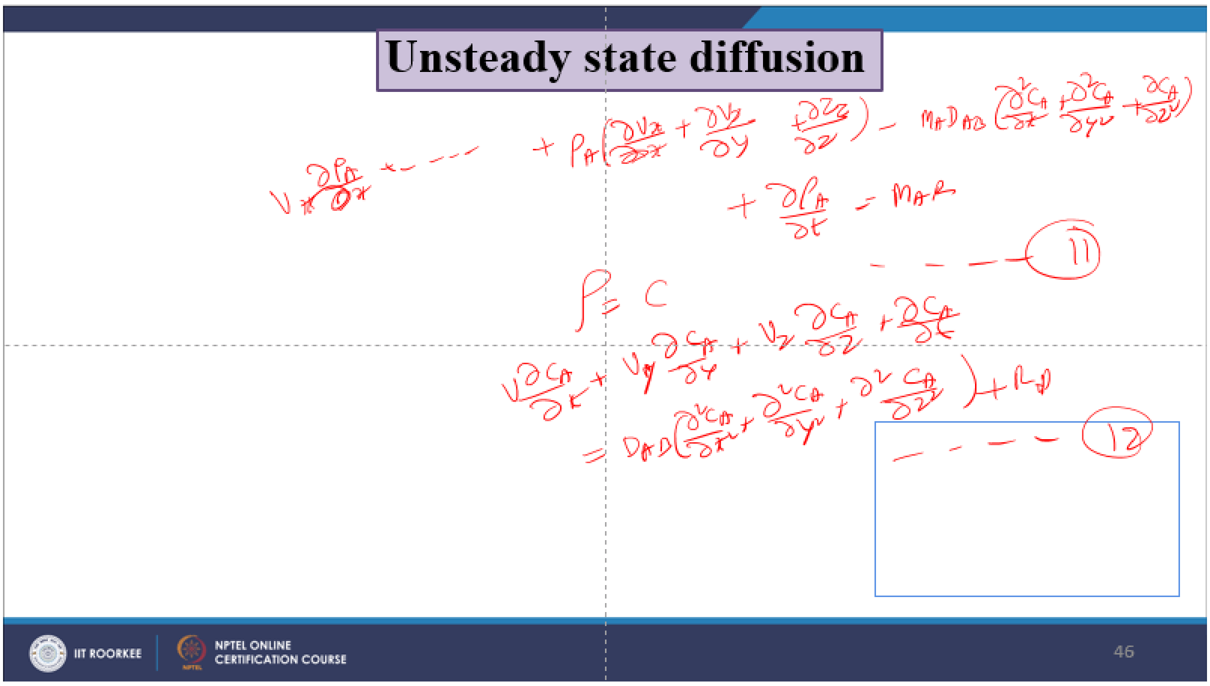


So, if we substitute, so, it can become M A N A plus M B N B over del X is equal to del V X over del X plus V X del over rho del X. This is equation number 8. So, if we substitute equation 8 into equation 7, we get del V X over del X plus del V Y over del Y plus del V Z over del Z plus V X del rho del X plus V Y del rho over del Y plus V Z del rho del Z plus d rho d del d q.

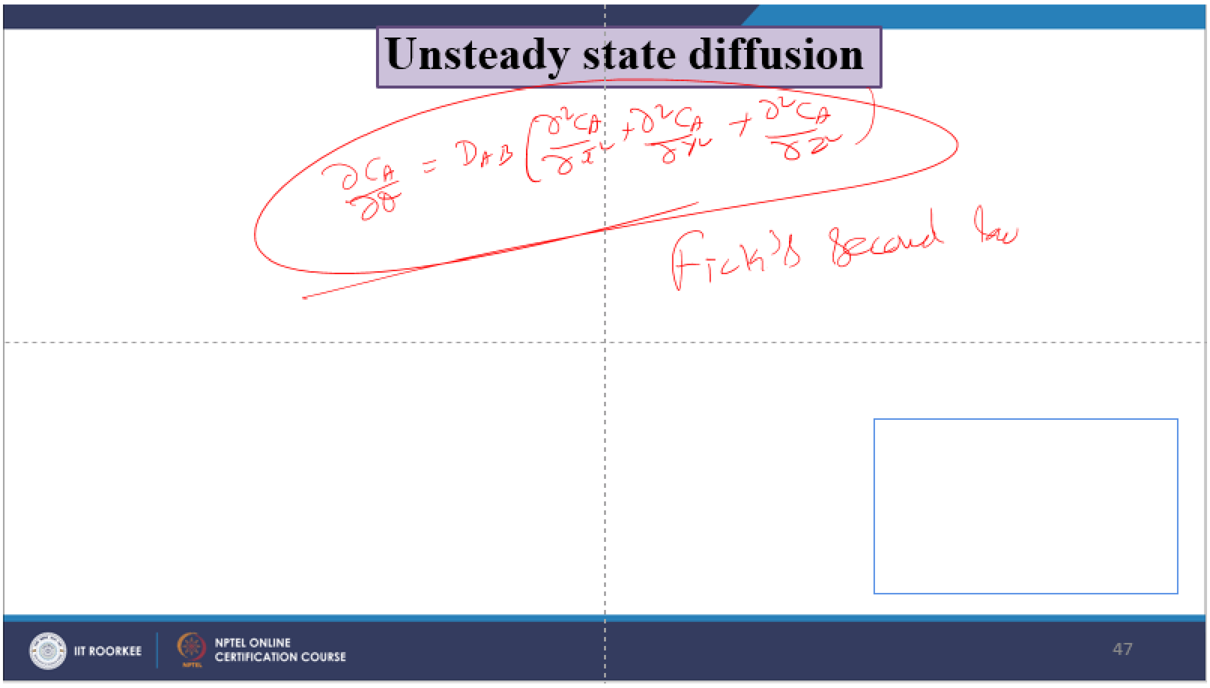
This is equal to 0. This is equation number 9. Now, this is the equation of continuity or the mass balance for total substance. Now, if solution density is constant, then equation 9, we have del V X over del X plus del V Y is del Y plus del V Z del Z is equal to 0.



This is equation number 10. So, we know that in terms of mass flux and in the X direction, N A X is equal to N X A plus j A X. Now, if we substitute the value of and if we put on all those things, then it becomes M A N A X is equal to M A N X A plus M A Z A X or M A N A X is equal to M A C V X C A over C plus M A Z A X.



And this comes out to be M A del N A X over del X is equal to V X del rho A over del X plus rho A del V A over del X plus M A del j X j X plus del X and this is V X del rho A over del X plus rho A del V X over del X plus M A, sorry minus M A D A V del 2 C A over del X 2. Then equation 5 becomes V X del rho A del X and so on plus rho A del V X over del X plus del V Y over del Y plus del V Z del Z minus M A D A B del 2 C A over del X 2 plus del 2 C A over del Y 2 plus del C A over del Z 2 plus del rho A over del t is equal to M A r A. This is the equation number 11. Now when rho is constant, so if you use the equation 10 and dividing M A in equation 11, this can become V del C A over del X plus V Y del C A over del Y plus V Z del C A over del Z plus del C A over del t which is equal to D A B del 2 C A over del X 2 plus del 2 C A over del Y 2 plus del 2 C A over del Z 2 plus r A.



This can become the equation 12. So, in a special case where the velocity equal to the 0 and no chemicalization occurs, so from equation 12, we get del C A over del theta is equal to D A B del 2 C A over del X 2 plus del 2 C A over del Y 2 plus del 2 C A over del Z 2 and this is the Fick's second law. It is frequently applicable to the diffusion in solid and to limited situation in fluids.

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So dear friends, in this particular segment we discussed about the various mass transfer segments and operation which are useful in the polymer processing and for your convenience we have been listed several references which you can utilize. Thank you very much.