Polymer Process Engineering
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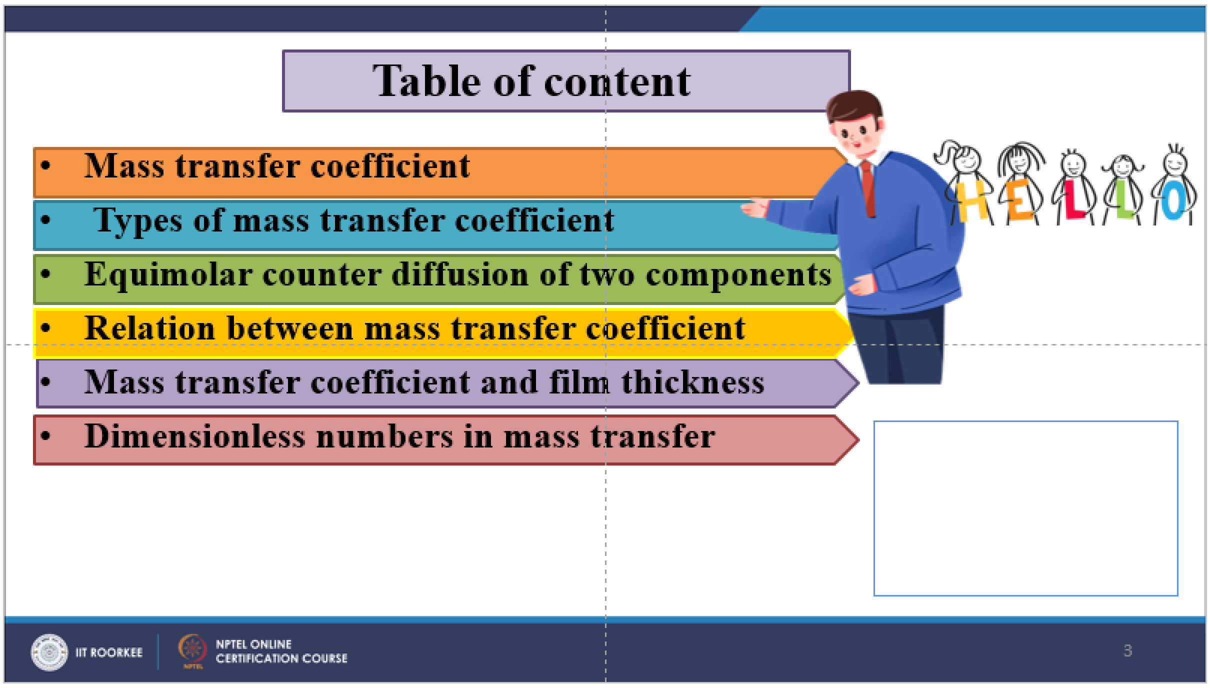
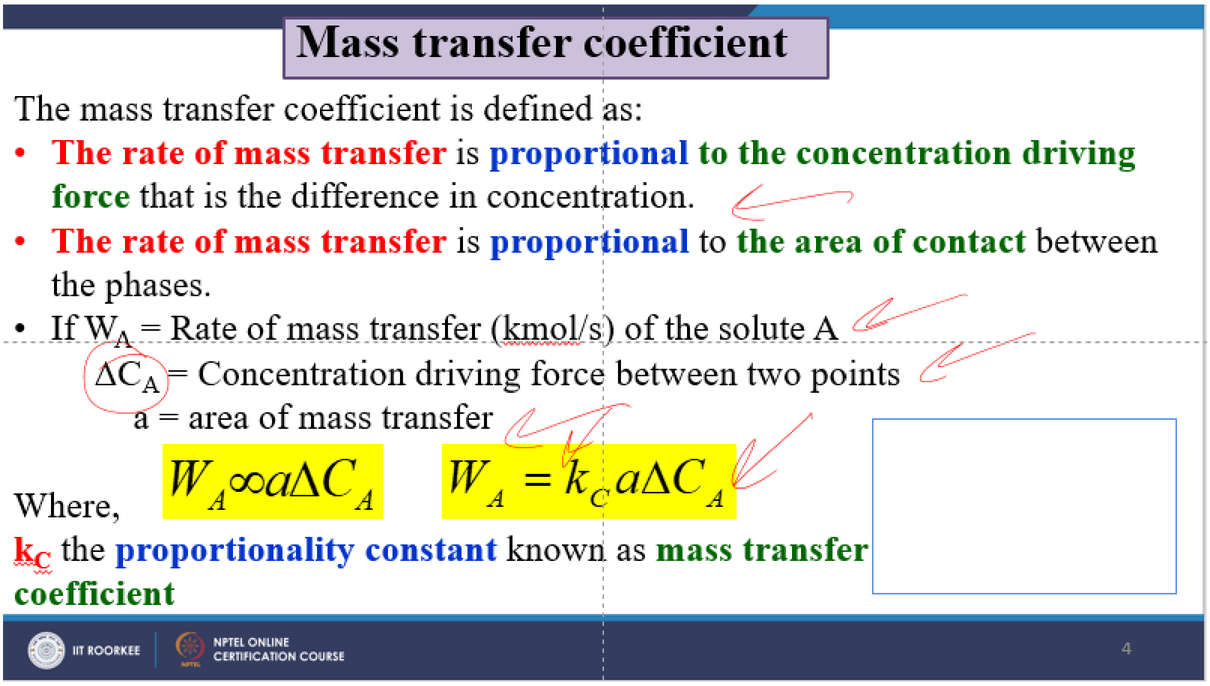
Lecture – 23
Mass transfer phenomenon in polymers: Mass transfer coefficient and dimensionless numbers

Welcome to the mass transfer coefficient and dimensionless numbers. We are going to discuss about the mass transfer phenomena in polymer section. Now, we have covered the steady state diffusion through the constant area in the previous lecture apart from this we discussed about the non-diffusing components and we discussed about the steady state diffusion through the variable area. We had several problems to solve numerical problems for your convenience. Then we discussed about the diffusion from a sphere and equimolar counter diffusion.



In this particular segment, we are going to discuss about the mass transfer coefficient and different types of mass transfer coefficient and we will discuss about the equimolar counter diffusion for 2 components and we will discuss about the relation between the mass transfer coefficient and mass transfer coefficient and film thickness and we will describe about the dimensionless numbers in mass transfer.



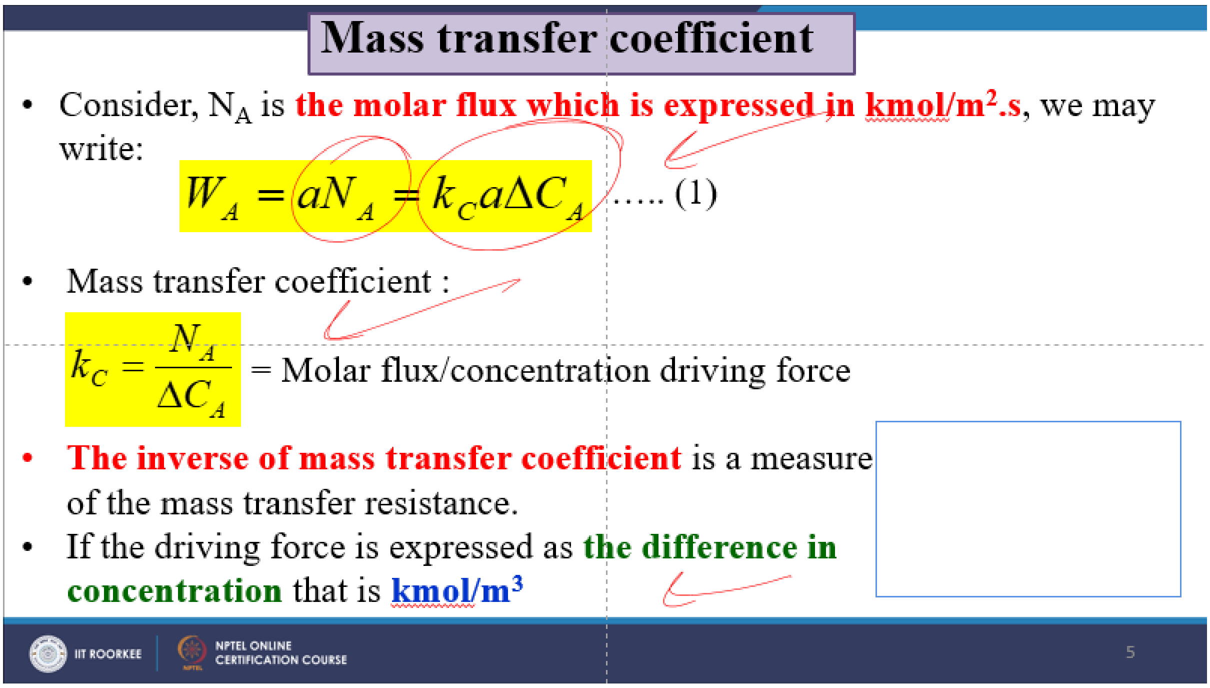
$W_A \propto a\Delta C_A$

$$W_A = k_C a\Delta C_A$$

Where,

k_C the **proportionality constant** known as **mass transfer coefficient**

Now, the mass transfer coefficient this is defined as the rate of mass transfer which is proportional to the concentration driving force and that is a difference in the concentration. Apart from this, the rate of mass transfer is again proportional to the area of contact between the phases.



the molar flux which is expressed in kmol/m^2.s

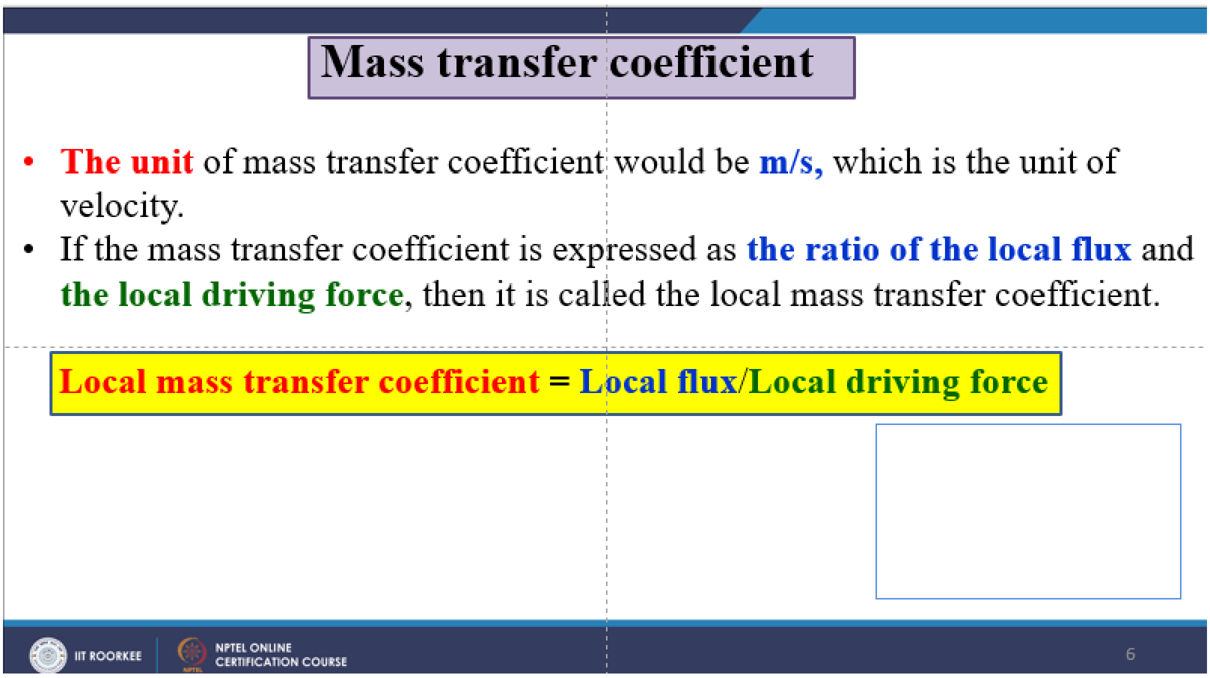
$$W_A = aN_A = k_C a \Delta C_A$$

Mass transfer coefficient

$$k_C = \frac{N_A}{\Delta C_A}$$

So, if we represent W A as a rate of mass transfer of a solute A and the concentration driving force between the 2 points can be given as delta C A and area of mass transfer then mathematically we can represent like W A is equal to k C A delta C A where k C is the proportionality constant and this is known as the mass transfer coefficient. Now, if we consider this N A is the mole flux which is expressed in kilo mole per meter square we may write that W A is equal to A N A into k C A is equal to k C A delta C A which is equation number 1 and the mass transfer coefficient can be represented as k C is equal to N A over delta C A that is the mole molar flux over concentration driving force.

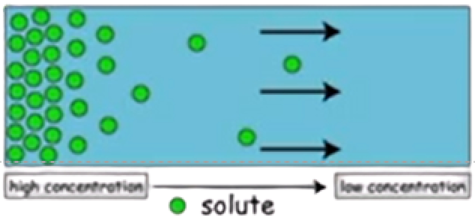
So, the inverse of mass transfer coefficient is a measure of the mass transfer resistance and if the driving force is expressed as a difference in the concentration and that can be represented in the units of kilo mole per meter cube. Now, the unit of mass transfer coefficient that would be meter per second which is the unit of velocity, if the mass transfer coefficient is expressed as a ratio of the local flux and the local driving force then it is called the local mass transfer coefficient.



So, the local mass transfer coefficient is equal to the local flux over local driving force. Now, when it is expressed as a ratio of the average flux over surface and the average driving force then it is known as the average mass transfer coefficient and average mass transfer coefficient can be represented mathematically is the average flux over average driving force.

Types of mass transfer coefficient

- **Convective mass transfer** can occur in a **gas or in a liquid medium**, but it **does not occur in the solid medium**.
- A few choices of the driving force can be:



a) Difference in concentration
b) Difference in partial pressure
c) Difference in molar fraction

- But in case of **the heat transfer the temperature difference is the only driving force.**

Now, there are different type of mass transfer coefficients, one is the convective mass transfer, this can occur in a gas or in a liquid medium, but it does not occur in the solid media. There are few choices of the driving force, this can be the difference in the concentration, the difference in the partial pressure and difference in the molar fraction. But in case of heat transfer, the temperature difference is the only driving force. Now, the different type of mass transfer coefficient have been defined, this depends on whether the mass transfer occur in a gas phase or in a liquid phase, then the choice of driving force, then whether it is a case of diffusing of component A through a non-diffusing B or whether it is an accumular counter current diffusion or counter diffusion.

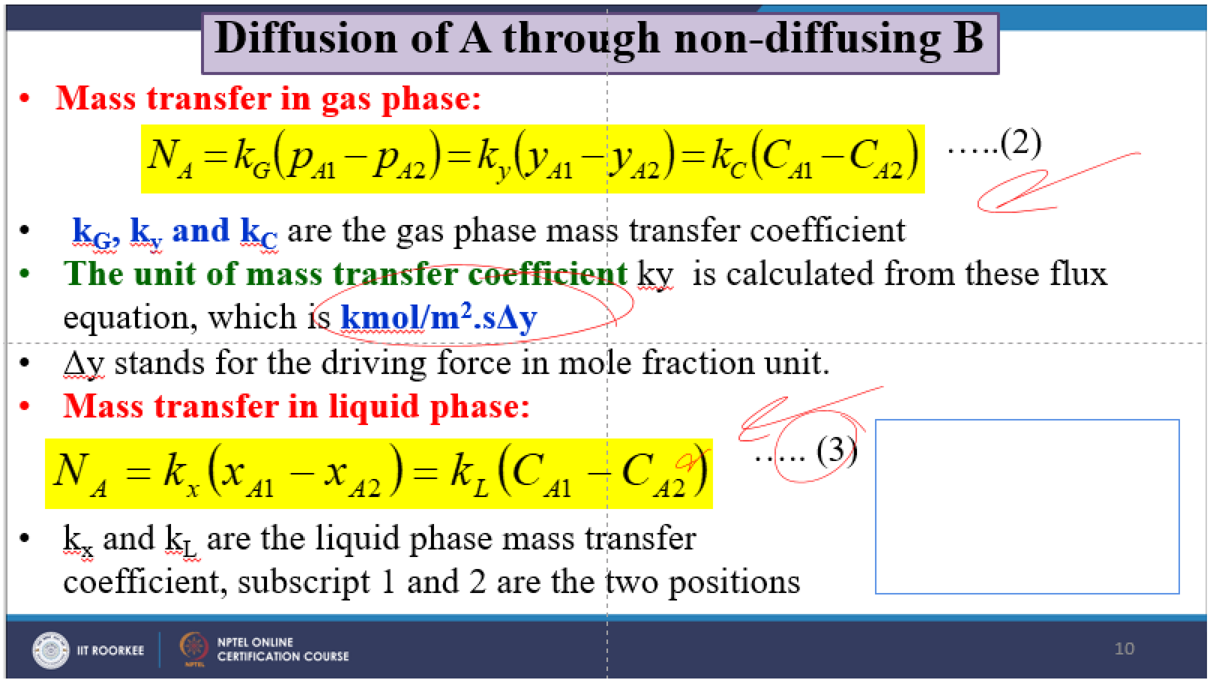
Types of mass transfer coefficient

- **Different type of mass transfer coefficient** have been defined depending upon:

a) whether the mass transfer occur in the gas phase or in the liquid phase.
b) choice of driving force
c) whether it is a case of diffusing of component A through non diffusing B or whether it is a equimolar counter current diffusion or the counter diffusion.

- If the transport of mass occur through a stagnant film of thickness δ, then:

Flux = mass transfer coefficient x driving force



Mass transfer in gas phase

$$N_A = k_G(p_{A1} - p_{A2}) = k_y(y_{A1} - y_{A2}) = k_C(C_{A1} - C_{A2})$$

- **k_G, k_y and k_C** are the gas phase mass transfer coefficient
- **The unit of mass transfer coefficient** ky is calculated from these flux equation, which is **kmol/m².sΔy**
- Δy stands for the driving force in mole fraction unit.

Mass transfer in liquid phase

$$N_A = k_x(x_{A1} - x_{A2}) = k_L(C_{A1} - C_{A2})$$

- k_x and k_L are the liquid phase mass transfer coefficient, subscript 1 and 2 are the two positions

Now, if transport of mass occur through a stagnant film of thickness say delta, then flux is equal to mass transfer coefficient into the driving force. So, if we talk about the diffusion of A through non-diffusing B, the mass transfer in gas phase can be given as per this equation number 2, that is NA is equal to Kg PA1 minus PA2 and that is equal to KY into YA1 minus YA2 and that is equal to Kc CA1 minus CA2 and Kg KY and Kc are the gas phase mass transfer coefficient and a unit of mass transfer coefficient KY is calculated from these flux equation and which is equal to the kilo mole per meter square second delta Y and delta Y stands for the driving force in the mole fraction unit and the mass transfer in the liquid phase can be given in the as per the equation number 3, where Kx and KL are the liquid phase mass transfer coefficient and subscript A and 1 and 2 are the 2 positions.

Diffusion of A through non-diffusing B

- **If the gas phase is ideal**: the concentration term of eq 2 is given by:

$$C_A = p_A/RT$$

Where, **p_A is the partial pressure of A**

- Suppose that the distance between the two locations 1 and 2 is δ (the film thickness). The expression of mass transfer coefficient can be obtained by comparing equation 2 with:

$$N_A = \frac{D_{AB} P_t}{RT(x_2 - x_1) p_{BLM}} (p_{A1} - p_{A2}) \quad \ldots(4)$$

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If gas phase is ideal

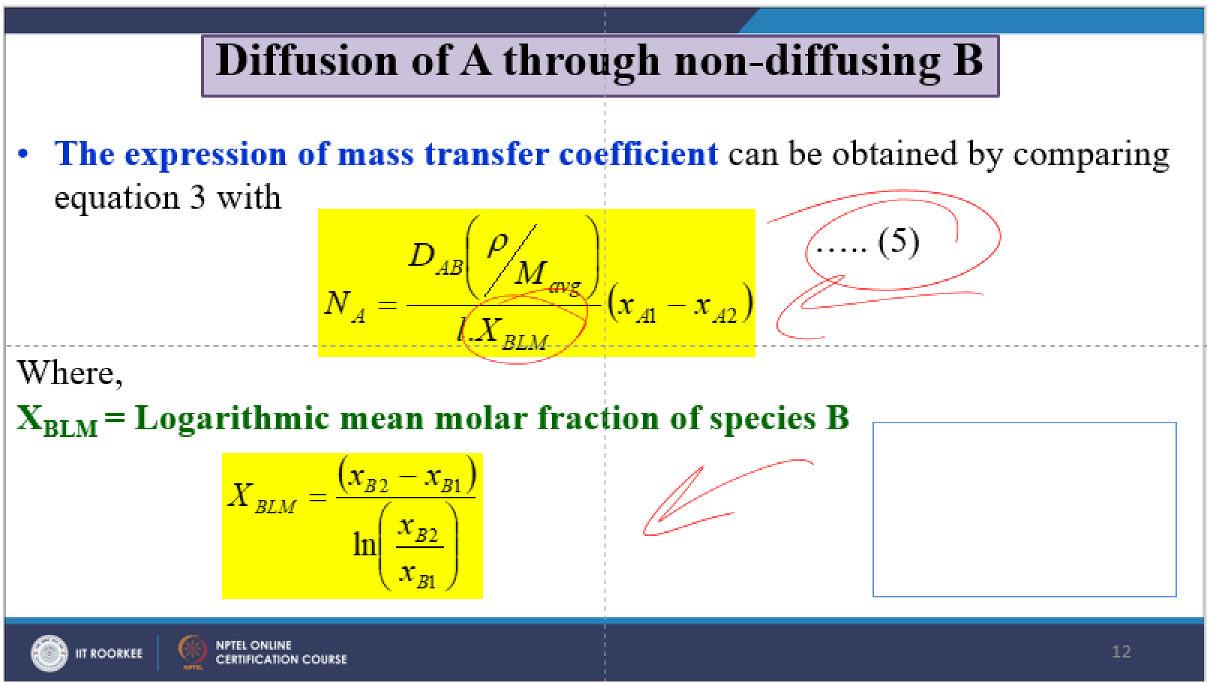
$C_A = p_A/RT$

Where, **p_A is the partial pressure of A**

The expression of mass transfer coefficient can be obtained by comparing equation 2

$$N_A = \frac{D_{AB} P_t}{RT(x_2 - x_1) p_{BLM}} (p_{A1} - p_{A2})$$

Now, if gas phase is ideal, the concentration term of this particular equation 2 can be given by CA is equal to PA over RT where PA is the partial pressure of A. Now, suppose that the distance between the 2 location A and B is delta and the film that is the film thickness, the expression of mass transfer coefficient can be obtained by comparing the equation 2 with this NA is equal to DAB P1 over RT into X minus X1 PBLM into PA1 minus PA2 that is equation number 4.



Expression of mass transfer coefficient

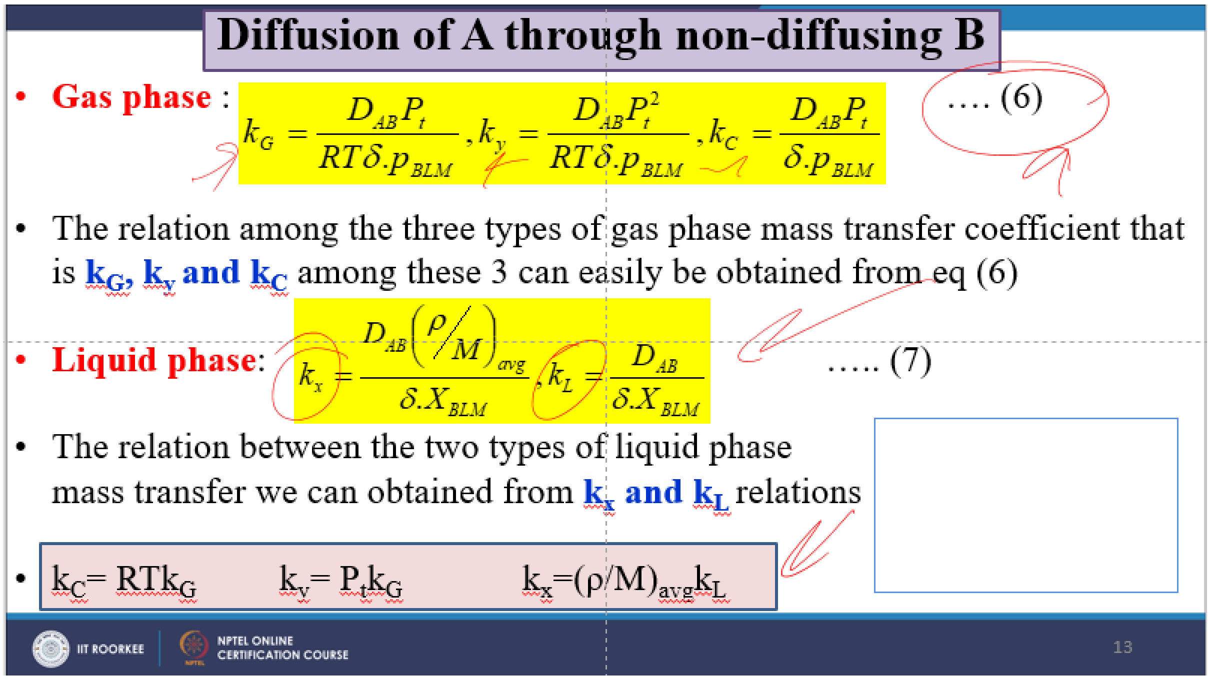
$$N_A = \frac{D_{AB}\left(\rho/M_{avg}\right)}{l.X_{BLM}}(x_{A1} - x_{A2})$$

Where,

X_{BLM} = Logarithmic mean molar fraction of species B

$$X_{BLM} = \frac{(x_{B2} - x_{B1})}{\ln\left(\frac{x_{B2}}{x_{B1}}\right)}$$

Now, the expression of mass transfer coefficient can be obtained by comparing this equation number 3 with this particular equation which is equation number 5. Now, here this XBLM that is a logarithmic mean molar fraction of a species B and this can be represented by this mathematical representation. Now, if we talk about the gas phase, the mathematical expression for different mass transfer coefficient is given by KG, KY and KC and these are presented as equation number 6.



Gas phase

$$k_G = \frac{D_{AB}P_t}{RT\delta.p_{BLM}}, k_y = \frac{D_{AB}P_t^2}{RT\delta.p_{BLM}}, k_C = \frac{D_{AB}P_t}{\delta.p_{BLM}}$$

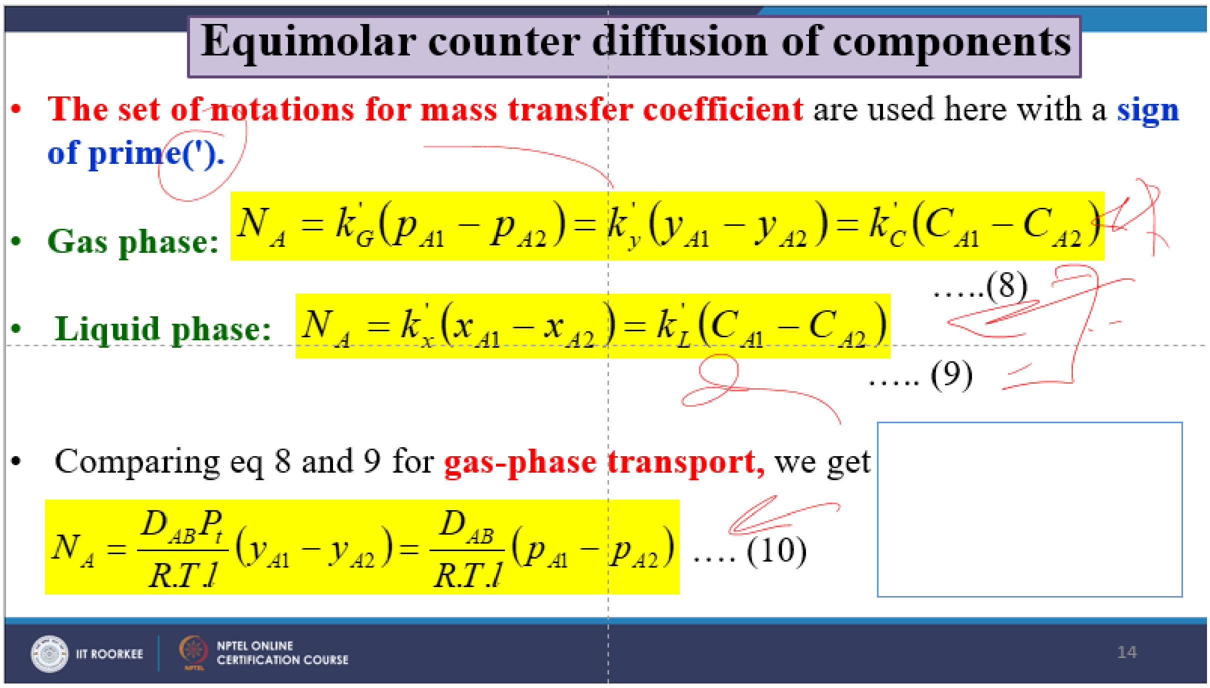
Liquid phase

$$k_x = \frac{D_{AB}(^{\rho}/_{M})_{avg}}{\delta.X_{BLM}}, k_L = \frac{D_{AB}}{\delta.X_{BLM}}$$

kx and kL relations

- $k_C = RTk_G$ $\quad k_y = P_tk_G$ $\quad k_x = (\rho/M)_{avg}k_L$

So, the relation among 3 type of a gas phase mass transfer coefficient that is KG, KY and KC among 3, these 3 can easily be obtained from this particular equation. Now, if we talk about the liquid phase, the mass transfer coefficient KX can be given on KL can be represented mathematically as per this particular equation number 7. So, the relation between the 2 types of liquid phase mass transfer we can obtain from KX and KL relations. So, this can be mathematically obtained by KC is equal to RTKG and K is equal to PTKG likewise. So, when we talk about the equimolar counter diffusion of component to set of notation for the mass transfer coefficient they are used here with the sign of prime.



For gas phase

$$N_A = k'_G(p_{A1} - p_{A2}) = k'_y(y_{A1} - y_{A2}) = k'_C(C_{A1} - C_{A2})$$

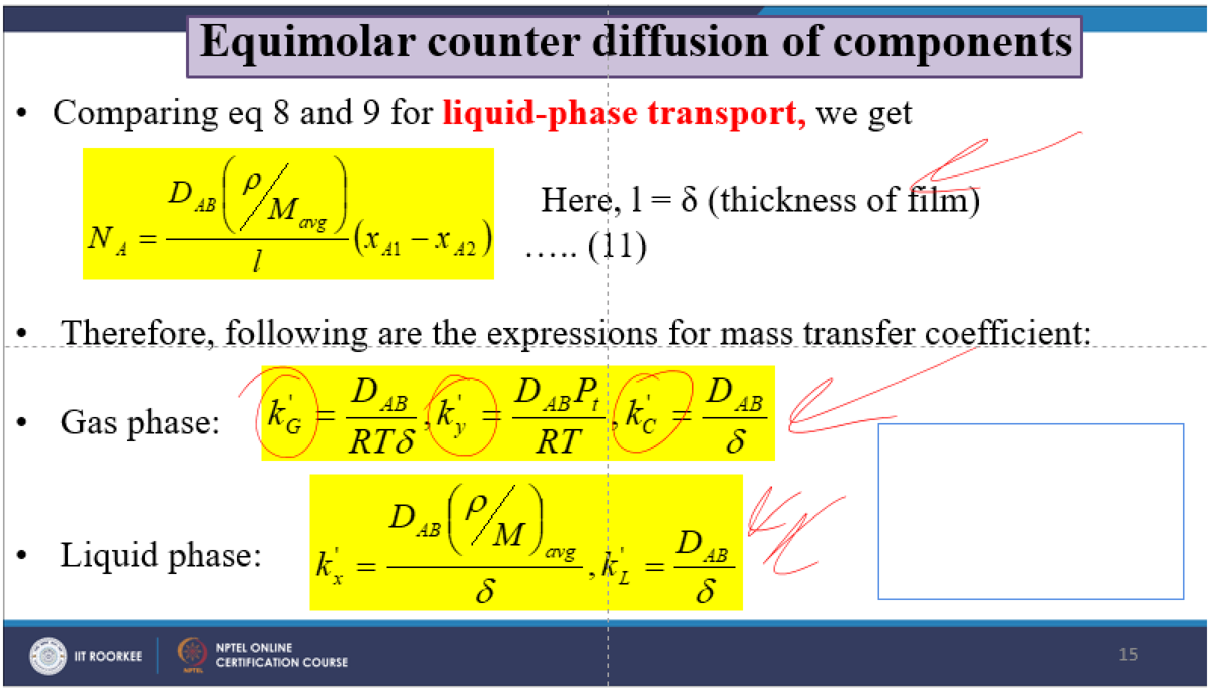
For liquid phase

$$N_A = k'_x(x_{A1} - x_{A2}) = k'_L(C_{A1} - C_{A2})$$

Gas phase transport

$$N_A = \frac{D_{AB}P_t}{R.T.l}(y_{A1} - y_{A2}) = \frac{D_{AB}}{R.T.l}(p_{A1} - p_{A2})$$

So, gas phase NA is equal to KG prime PA1 minus PA2 is equal to KY prime YA1 minus YA2 and this is equal to KC prime is into CA1 minus CA2 this is equation number 8. And if we talk about the liquid phase, then it can be mathematically represented as per the equation number 10. Now, if we compare both the equations for the gas phase transport, we get this equation that is NA is equal to DABPT over RT YA1 minus YA2 and that is equation number 10. Now, if we compare these equation 8 and 9 for liquid phase transport, so, we can get this NA equation and if we follow the different type of expression for the mass transfer coefficient. So, the for the gas phase, the KG prime and KY prime and KC prime can be given like this and for liquid phase, the KG prime is given as per this mathematical representation.



Liquid phase transport

$$N_A = \frac{D_{AB}\left(\rho/M_{avg}\right)}{l}(x_{A1} - x_{A2})$$

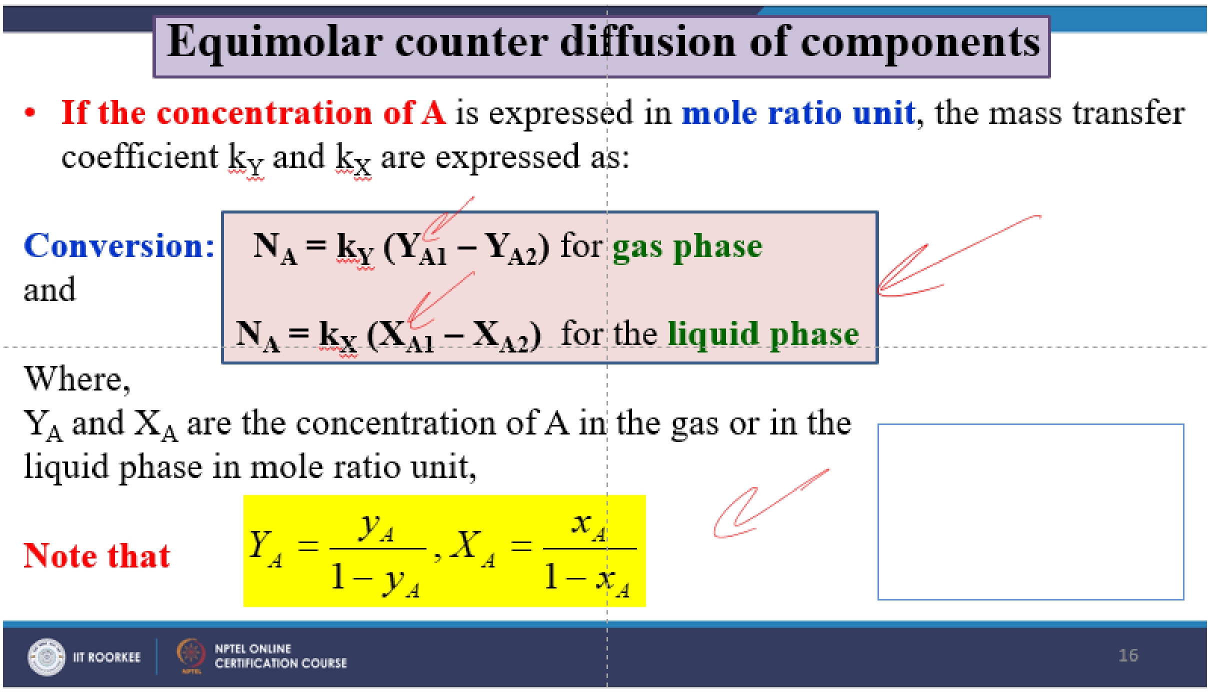
The expresions for mass transfer coefficient

For gas phase

$$k'_G = \frac{D_{AB}}{RT\delta}, k'_y = \frac{D_{AB}P_t}{RT}, k'_C = \frac{D_{AB}}{\delta}$$

For liquid phase

$$k'_x = \frac{D_{AB}\left(\rho/M\right)_{avg}}{\delta}, k'_L = \frac{D_{AB}}{\delta}$$

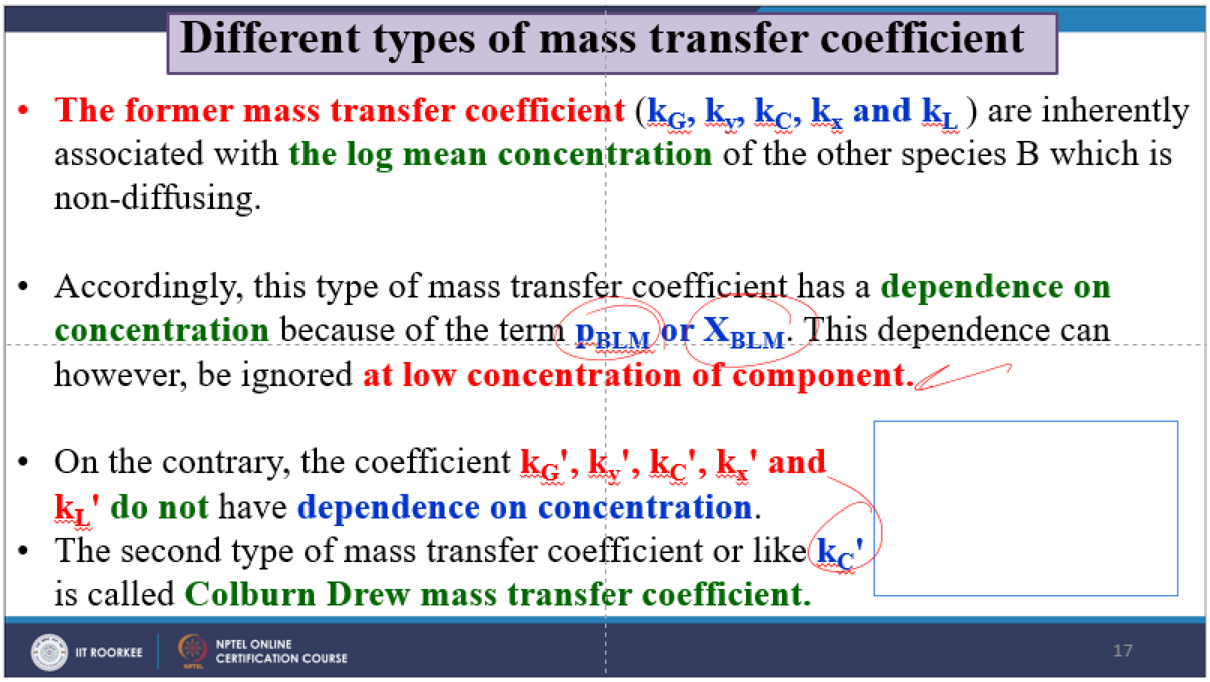


$N_A = k_Y (Y_{A1} - Y_{A2})$ for **gas phase**

$N_A = k_X (X_{A1} - X_{A2})$ for the **liquid phase**

$$Y_A = \frac{y_A}{1-y_A}, X_A = \frac{x_A}{1-x_A}$$

Now, if the concentration of A is expressed in mode ratio unit, the mass transfer coefficient KY and KX they are expressed as a conversion and this mathematically can be represented like this. Now, here the YA and XA they are the concentration of A in the gas or in the liquid phase in the mode ratio unit. So, therefore, YA is equal to YA into 1 minus YA into X and XA is equal to XA over X 1 minus XA.



Relation between k_G and k_y

$$y_{A1} - y_{A2} = \frac{p_{A1}}{P_t - p_{A1}} - \frac{p_{A2}}{P_t - p_{A2}}$$

$$= \frac{P_t p_{A1} - p_{A1} p_{A2} - P_t p_{A2} + p_{A1} p_{A2}}{(P_t - p_{A1})(P_t - p_{A2})} = \frac{P_t (p_{A1} - p_{A2})}{p_{B1} \, p_{B2}}$$

$$p_{A1} - p_{A2} = (y_{A1} - y_{A2}) \frac{p_{B1} p_{B2}}{P_t}$$

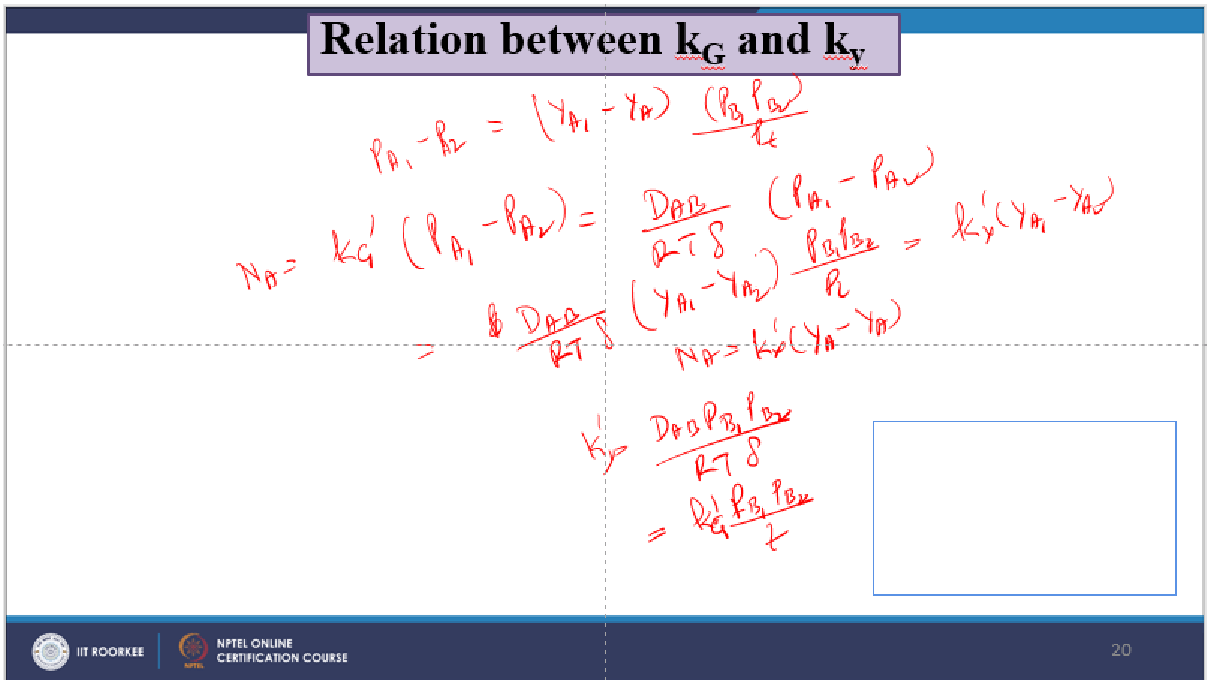
Relation between k_G and k_y

$$N_A = k_G (p_{A1} - p_{A2}) = \frac{D_{AB} P_t}{R T \delta \, p_{BLM}} (p_{A1} - p_{A2}) \frac{p_{B1} p_{B2}}{P_t} = k_y (y_{A1} - y_{A2})$$

$$= \frac{D_{AB} P_t}{R T \delta \, p_{BLM}} (y_{A1} - y_{A2})$$

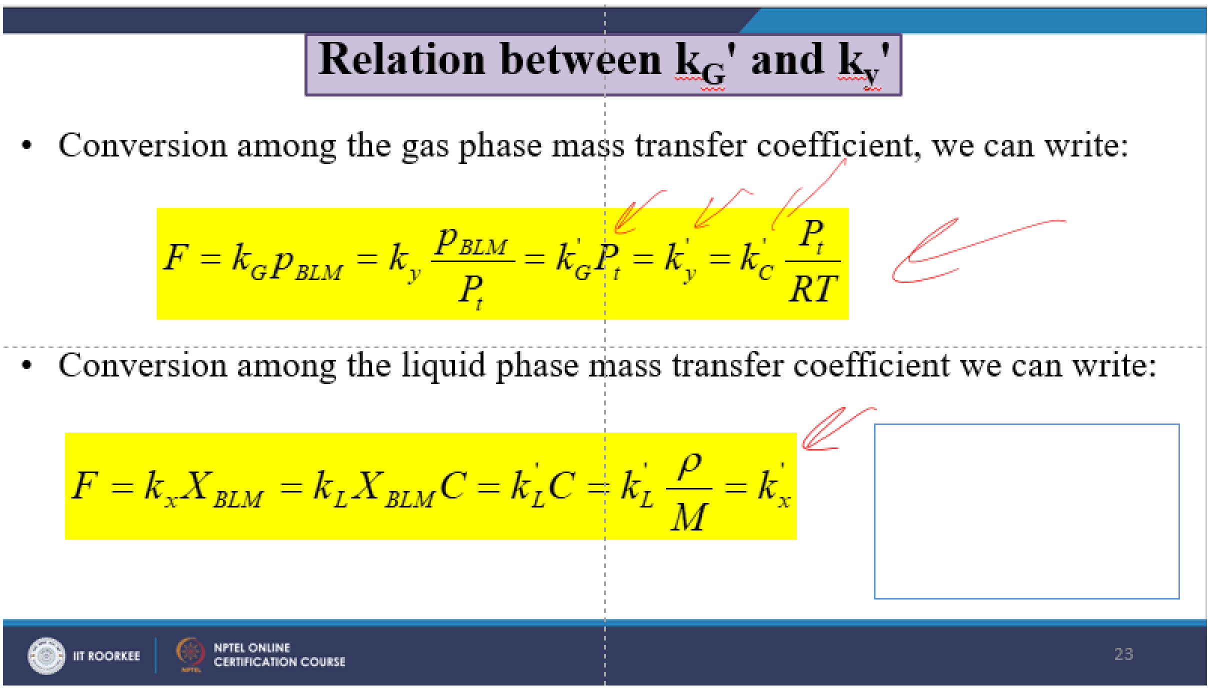
$$N_A = k_y (y_{A1} - y_{A2})$$

$$k_y = \frac{D_{AB} p_{B1} p_{B2}}{R T \, p_{BLM}} \Rightarrow k_G \frac{p_{B1} p_{B2}}{P_t}$$



Now, there are different type of mass transfer coefficients, a former mass transfer coefficient like KG, KY, KC, KX and KLR inherently associated with the log mean concentration of the other species B which is non-diffusing and as per this particular type of mass transfer coefficient, they has a dependency on the concentration because the term P BLM or X BLM this dependency can however be ignored at a low concentration of the component. Now, on the contrary, the coefficient KG prime, KY prime, KC prime, KX prime and KL prime do not have a dependency on the concentration and the second type of mass transfer coefficient KC prime that is called the Coulburn-Dreu mass transfer coefficient.

So, the driving force in case of mole ratio unit Y between the two points can be written as YA1 minus YA2 is equal to PA1 over PT minus PA1 minus PA2 over PT minus PA2 and that is equal to PT PA1 minus PA1 PA2 minus PT that is total PA1 the partial pressure at station of A at station 1 then PA1 PA2 over PT minus PA1 into PT minus PA2. This is PT into PA1 minus PA2 over PB1 PB2 and that comes out to be PA1 minus PA2 that is YA1 minus YA2 that is PB1 PB2 over PT. Now, we have NA is equal to KG PA1 minus PA2 dAb PT over RT delta P BLM, PA1 minus PA2 which is dAb PT RT delta P BLM YA1 minus YA2 and that is PB1 PB2 over PT that is KY YA1 minus YA2. Now, since NA is equal to KY YA1 minus YA2, we may write KY is equal to dAb PB1 PB2 over RT P BLM which is equal to KG PB1 PB2 PT. So, similar relation between the KG prime and KY prime in case of equimolar counter diffusion this applies.



Conversion among the gas phase mass transfer coefficient

$$F = k_G p_{BLM} = k_y \frac{p_{BLM}}{P_t} = k_G' P_t = k_y' = k_C' \frac{P_t}{RT}$$

Conversion among the liquid phase mass transfer coefficient

$$F = k_x X_{BLM} = k_L X_{BLM} C = k_L' C = k_L' \frac{\rho}{M} = k_x'$$

So, we know that this PA1 minus PA2 that is equal to YA1 minus YA2 into PB1 PB2 over PT. So, now we have NA is equal to KG prime PA1 minus PA2 which is equal to dAb RT delta P A1 minus P A2 this is P sorry dAb over RT delta YA1 minus YA2 PB1 PB2 over PT which is equal to KY prime YA1 minus YA2. Now, since NA is equal to KY prime YA1 minus YA2 we may write KY prime is equal to dAb PB1 PB2 over RT delta and that is KG prime is PB1 PB2 over PT. So, now the conversion among the gas phase mass transfer coefficient we can write all these things like this F is equal to KG BLM is equal to KY P BLM PT is equal to KG prime PT K is equal to KY prime equal to KC prime PT over RT and if it conversion among the liquid phase mass transfer coefficient we can write like this.

Values of mass transfer coefficient and film thickness

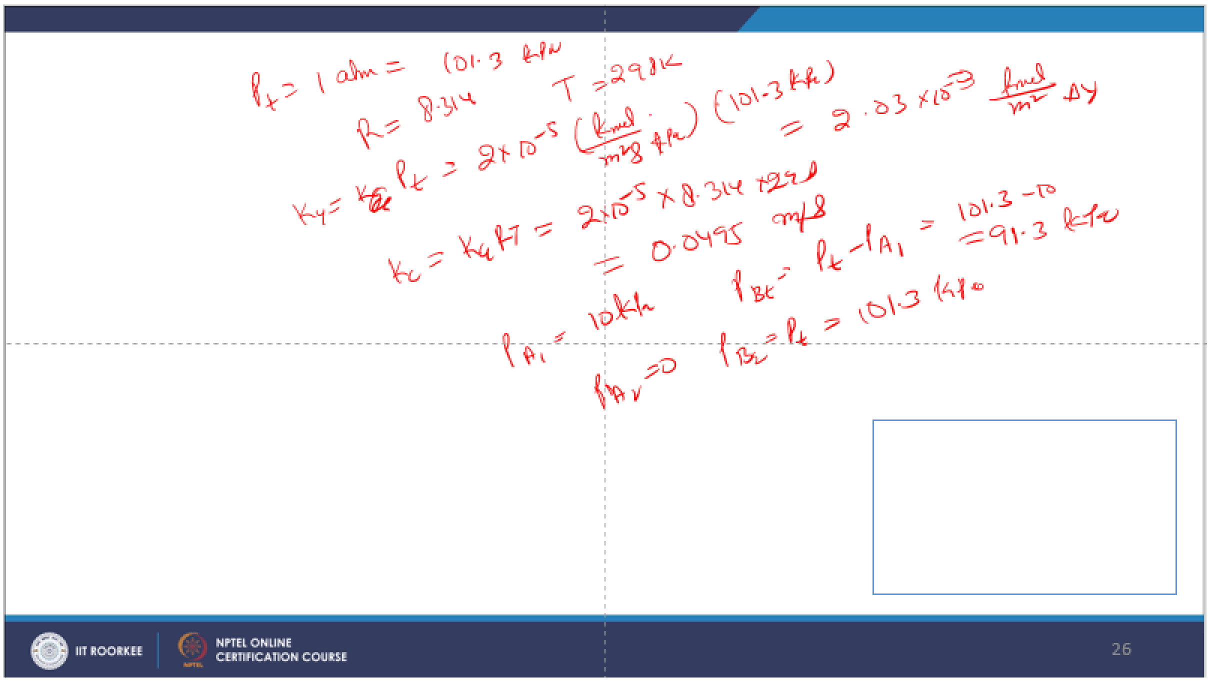
- **For gas phase** mass transfer coefficient, **$k_C \sim 10^{-2}$ m/s** and **the film thickness δ ~1 mm.**
- **For liquid phase** mass transfer coefficient, **$k_C \sim 10^{-5}$ m/s** and the **film thickness δ ~0.1 mm.**

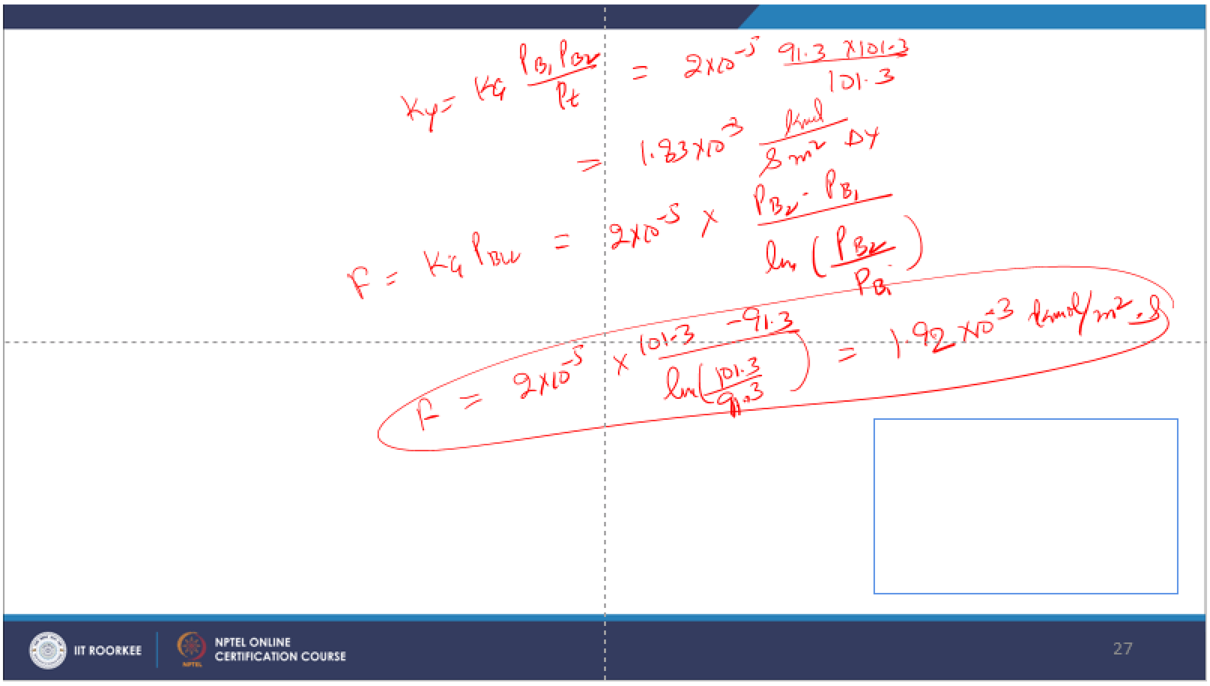
Now, for gas phase mass transfer coefficient KC is almost equal to 10 to the power minus 2 meter per second and the film thickness is delta is about 1 mm.

For liquid phase the mass transfer coefficient KC is around 10 to the power minus 5 meter per second and the film thickness is around delta thickness is 0.1 mm.

Problem-1

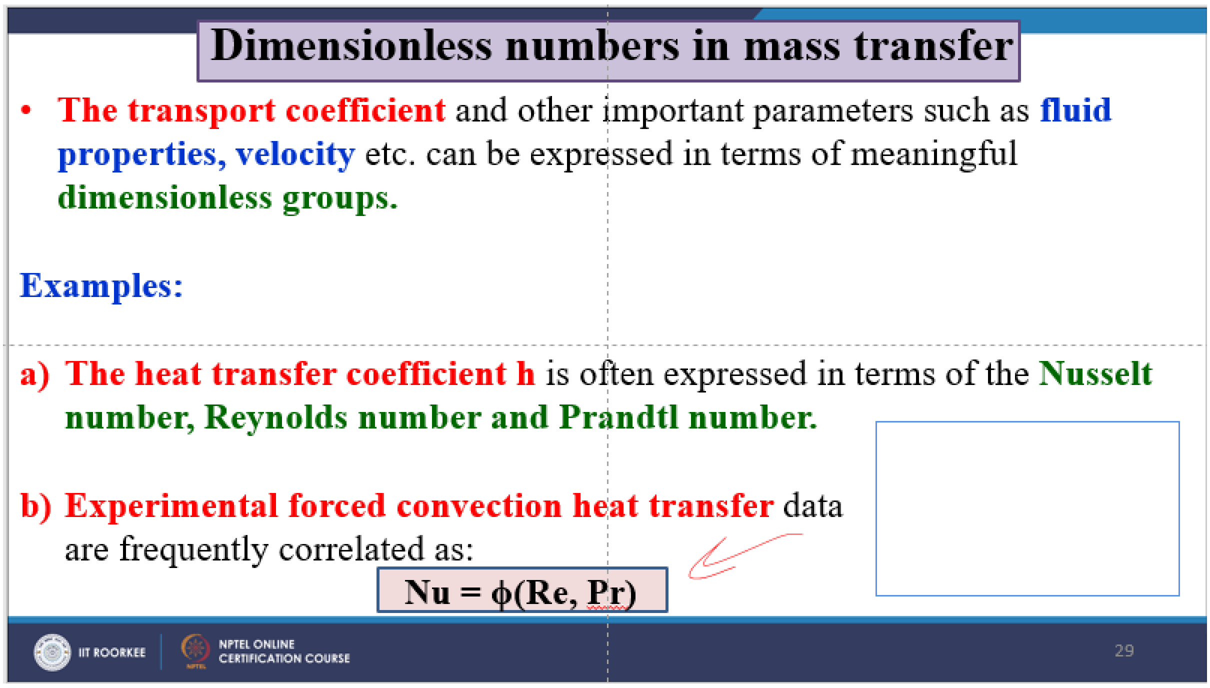
Question: Large volume of nitrogen gas (N_2) at atmospheric pressure is flowing over a pool of liquid of methanol, which is evaporating. Nitrogen is assumed to be insoluble in liquid. The gas phase mass transfer coefficient of methanol which is k_G is 2 x10^{-5} kmol/m^2.s kPa. Assume vapour pressure of methanol at 298 K is 10 kPa. Calculate k_Y, k_C, k_Y and F.





Now, let us take up another problem and that is a large volume of nitrogen gas at atmospheric pressure is flowing over a pool of liquid methanol which is evaporating and nitrogen is assumed to be insoluble in liquid and the gas phase mass transfer coefficient of methanol which is KG is 2 into 10 to the power minus 5 kilo mole per meter square second kilo Pascal and assuming the vapor pressure of methanol at 298 Kelvin is 10 kilo Pascal you need to calculate the KY KC K and F. So, in this case the diffusion of methanol occurs through a non-diffusing N2. So, given that PT is equal to 1 atmosphere that is 101.3 kilo Pascal, R is equal to 8.314, T is equal to 298 Kelvin. So, KY is equal to KG PT and that is equal to 2 into 10 to the power minus 5 kilo mole kilo Pascal into 101.3 kilo Pascal and which is comes out to be 2.03 into 10 to the power minus 3 kilo mole meter square delta y.

Now, KC is equal to KG RT which is equal to 2 into 10 to the power minus 5 into 8.314 into 298 which comes out to be 0.0495 meter per second. Now, PA1 is equal to 10 kilo Pascal and PB is equal to PT minus PA1 that is 101.3 minus 10 which is 91.3 kilo Pascal and PA2 is equal to 0 that is PB2 is equal to PT which is 101.3 kilo Pascal. So, KY is equal to KG PB1, PB2 over PT that is 2 into 10 to the power minus 5 into 91.3 into 101.3 over 101.3 and that is 1.83 into 10 to the power minus 3 kilo mole delta y. Now, F is equal to KG PBLM which is 2 into 10 to the power minus 5 into PB2 minus PB1 over ln PB2 over PB1. This is equal to 2 into 10 to the power minus 5 into 101.3 minus 91.3 over ln 101.3 over 91.3, 1.92 into 10 to the power minus 3 kilo mole per meter square second and this is our answer.



Now, there are so many dimensionless numbers in mass transfer operation, the transport coefficient and other important parameters like fluid, properties, velocity, these can be expressed in terms of meaningful dimensionless groups. For example, the heat transfer coefficient H is often expressed in terms of a Nusselt number, Reynolds number and Prandtl number.

Dimensionless numbers in mass transfer

- **The resulting correlation** may be used to estimate **the heat transfer coefficient** for any other set of process conditions and system parameters.
- The most important equations which relates **the Nusselt number with the Reynolds number and Prandtl number** is the **Dittus-Boelter equation.**
- Here we have **two most important dimensionless group:**

a) **The Sherwood number** which is the mass transfer **analogue of the Nusselt number.**
b) **The Schmidt number** which is the mass transfer **analogue of the Prandtl number**

Now experimental forced convection heat transfer data, they are frequently correlated with the Nusselt number is proportional to the Reynolds number and Prandtl number. Now, the resulting correlation may be used to estimate the heat transfer coefficient for any other set of process condition and system parameters. The most important equation which relates the Nusselt number with the Reynolds number and Prandtl number is the Dittus-Boelter equation. Now, here we have two most important dimensionless group, one is the Sherwood number which is the mass transfer analogous of Nusselt number and second one is the Schmidt number which is the mass transfer analogous of Prandtl number. Now, the origin of Sherwood and Schmidt can be traced by the analogy with the Nusselt and Prandtl number respectively.

Dimensionless numbers in mass transfer

- The origin of **Sherwood and Schmidt can be traced by analogy with Nusselt and Prandtl number** respectively.
- In heat transfer the Nusselt number is

Nu = Convective heat flux / Heat flux for conduction through a stagnant medium of thickness l for the same ΔT

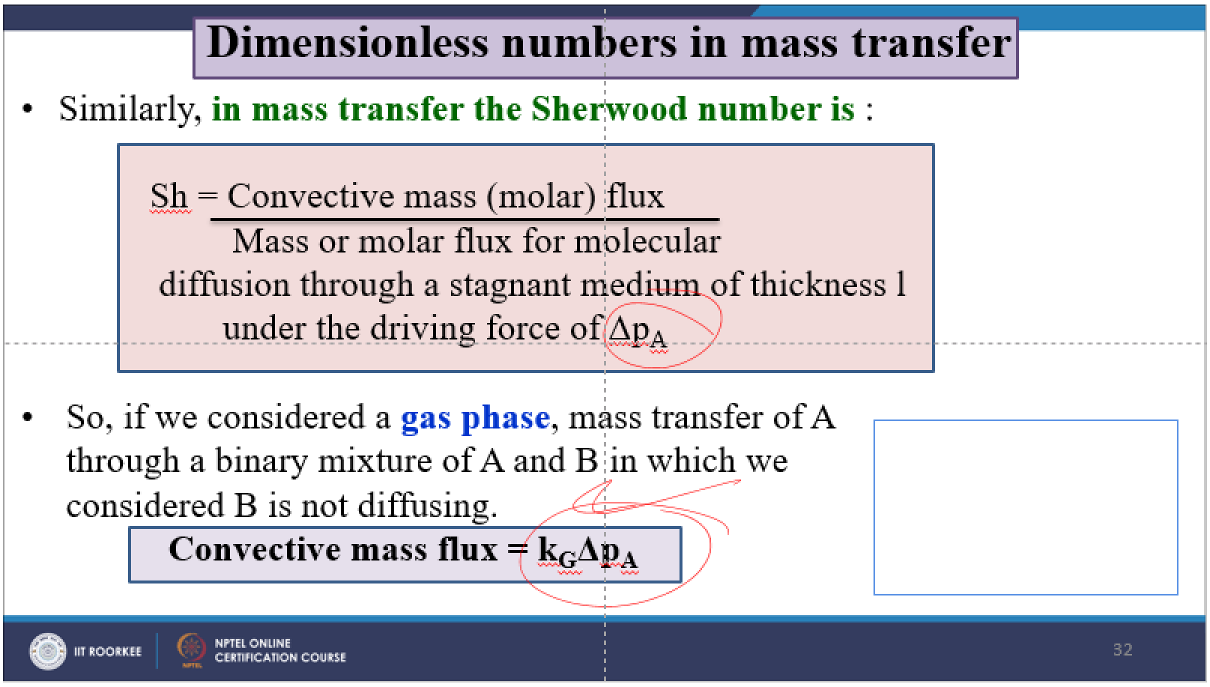
$$Nu = \frac{h\Delta T}{\left(k/l\right)\Delta T} = \frac{hl}{k}$$

where k= thermal conductivity

$$Nu = \frac{h\Delta T}{\left(k/_{l}\right)\Delta T} = \frac{hl}{k}$$

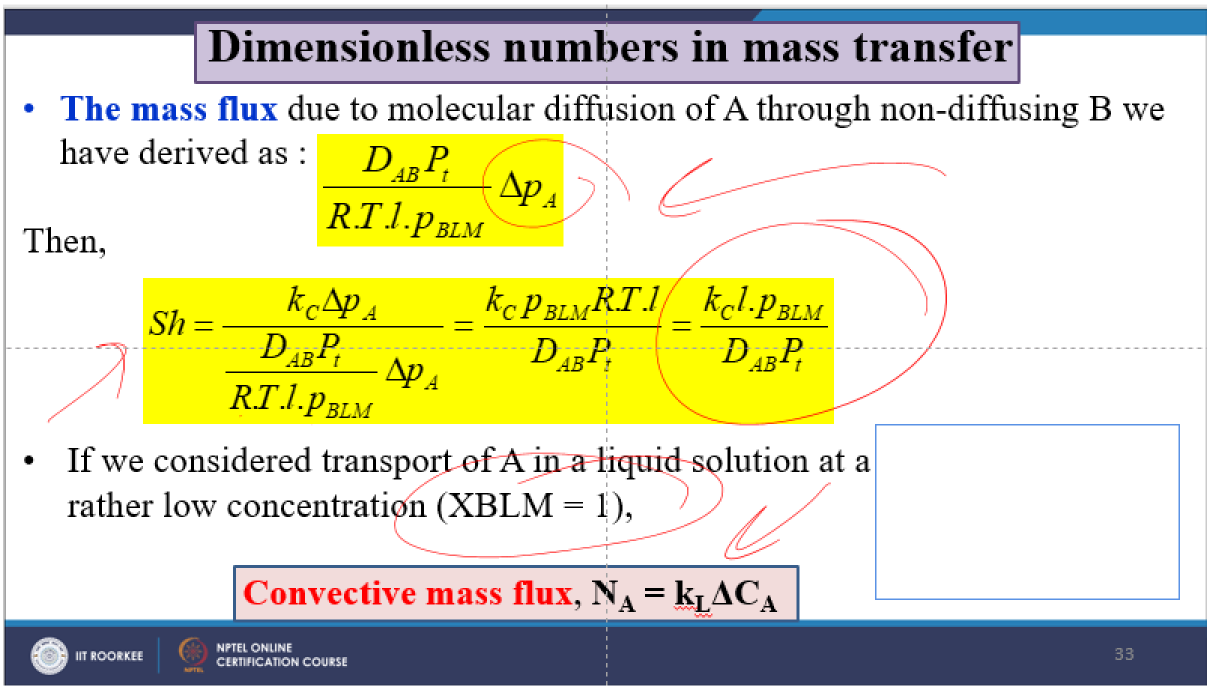
Where, k is thermal conductivity

In heat transfer, the Nusselt number is equal to the convective heat transfer over heat flux for conduction through a stagnant medium of thickness 1 for the same delta t and this can be mathematically represented like Nusselt number H is equal to H delta t over k over L into delta t and that is H L k over k, where k is the thermal conductivity.



Convective mass flux = $k_G \Delta p_A$

Similarly, the mass transfer of Sherwood number is the convective mass transfer or mass or molar flux over mass or molar flux at molecular diffusion through a stagnant number of thickness 1 under the driving force of delta p A.



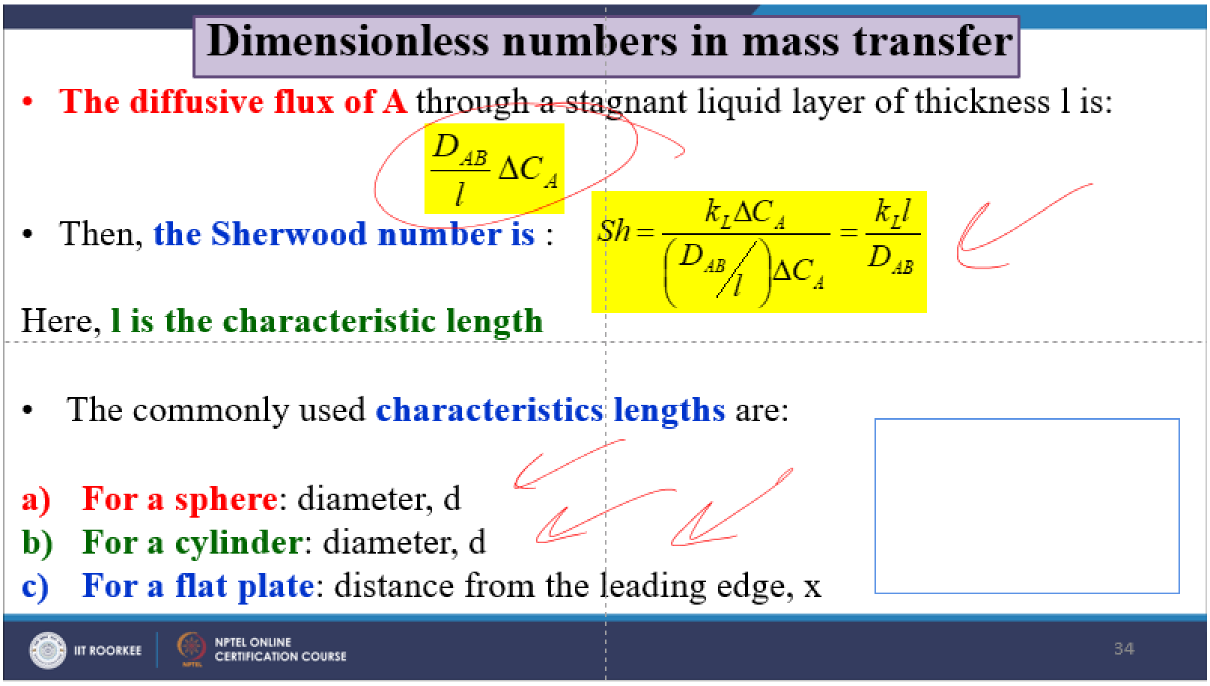
Mass flux due to molecular diffusion of A through non-diffusing B we have

$$\frac{D_{AB}P_t}{R.T.l.p_{BLM}}\Delta p_A$$

$$Sh = \frac{k_C \Delta p_A}{\frac{D_{AB}P_t}{R.T.l.p_{BLM}}\Delta p_A} = \frac{k_C p_{BLM} R.T.l}{D_{AB}P_t} = \frac{k_C l.p_{BLM}}{D_{AB}P_t}$$

Convective mass flux, $N_A = k_L \Delta C_A$

So, if we consider the gas phase mass transfer of A through the binary mixture of A and B in which we consider B is not diffusing to convective mass transfer flux can be represented as k g delta p A. Now, the mass flux due to the molecular diffusion A through non diffusing B, we have derived as D AB p t over RT L p v l m into delta p A and the Sherwood number can be represented as k c delta p A over D AB p t over RT L p v l m delta p and which is in general can be represented as k c L p v l m over D AB p t. Now, if we consider the transport of A in a liquid solution and at a rather low concentration that is X by L m is equal to 1.



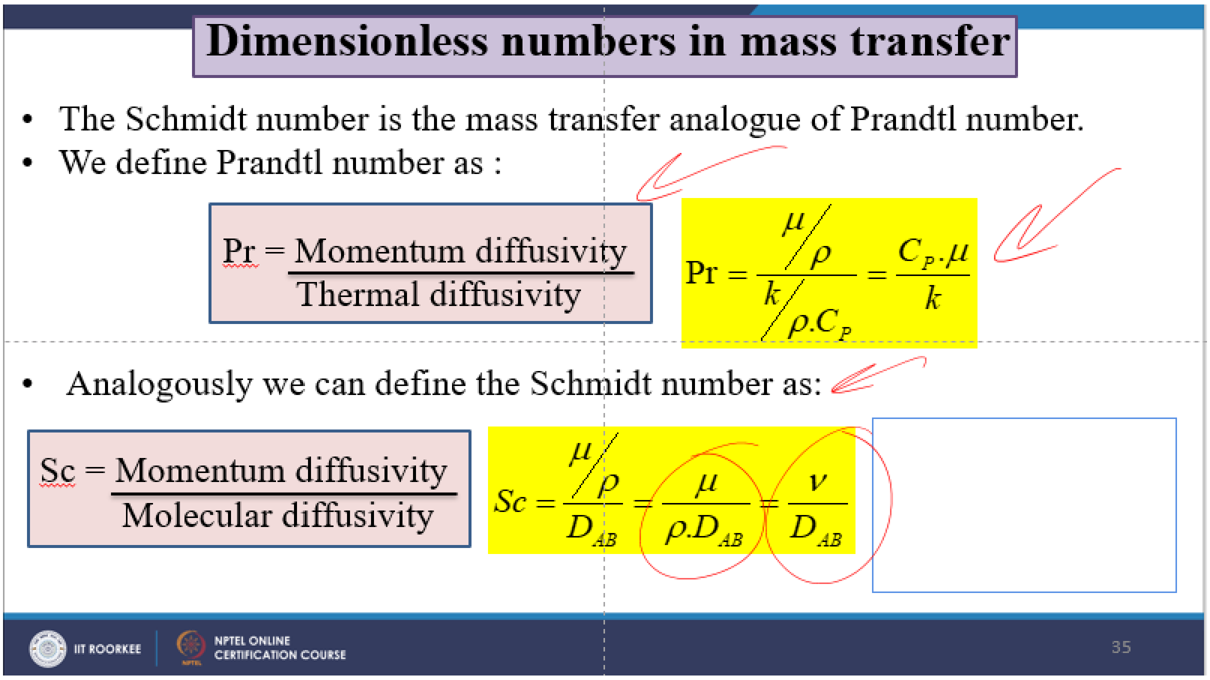
$$\frac{D_{AB}}{l}\Delta C_A$$

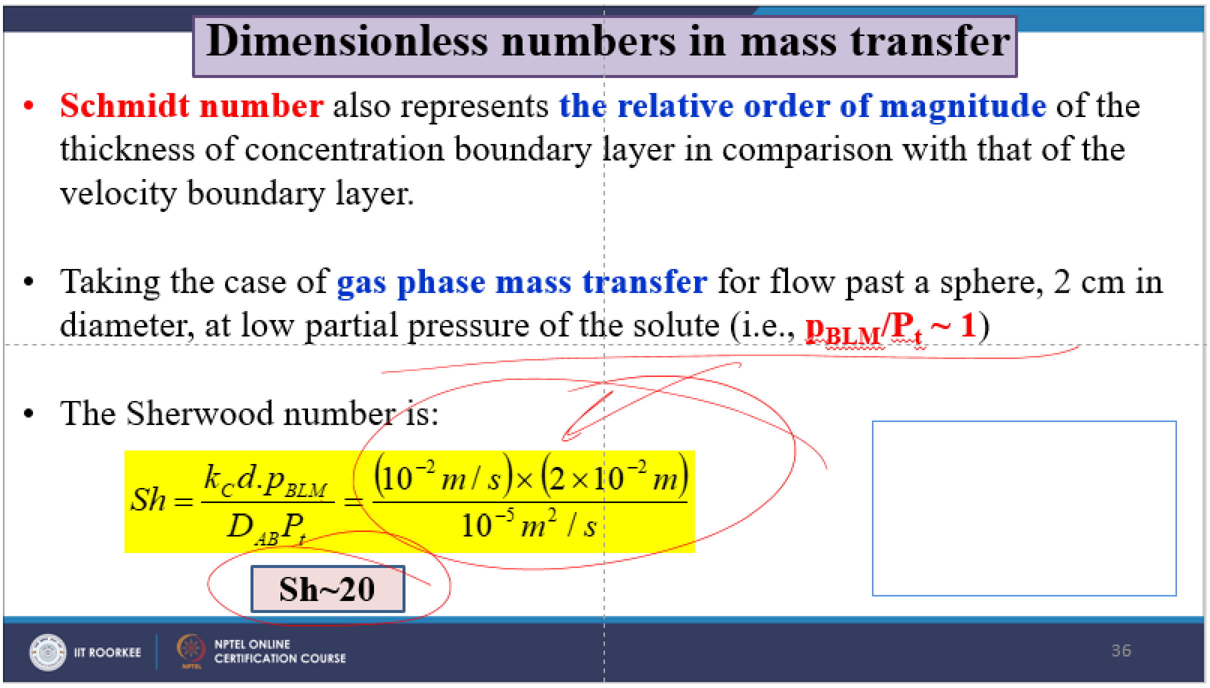
$$Sh = \frac{k_L \Delta C_A}{\left(D_{AB}/l\right)\Delta C_A} = \frac{k_L l}{D_{AB}}$$

So, convective heat convective mass flux can be represented as n A is equal to k L delta c A. Now, the diffusive flux of A through a stagnant liquid layer of thickness 1 can be represented as D AB over L into delta c, then the Sherwood number can be represented like this. Here L is the characteristics length. Now, commonly used characteristic lengths are for sphere the diameter D, for cylinder the diameter D and for flat plate the distance from the leading edge that is represented as X and the Schmidt number is the mass transfer analogues of the Prandtl number and we define the Prandtl number as momentum diffusivity over thermal diffusivity and mathematically Prandtl number can be represented like p r is equal to C p mu over k. Now, analogically we can define a Schmidt number like momentum diffusivity over molecular diffusivity and which can be represented as mu over rho into D AB and mu over rho D AB which is equal to mu D AB.

$$\text{Pr} = \frac{\mu/\rho}{k/\rho . C_P} = \frac{C_P . \mu}{k}$$

$$Sc = \frac{\mu/\rho}{D_{AB}} = \frac{\mu}{\rho . D_{AB}} = \frac{\nu}{D_{AB}}$$

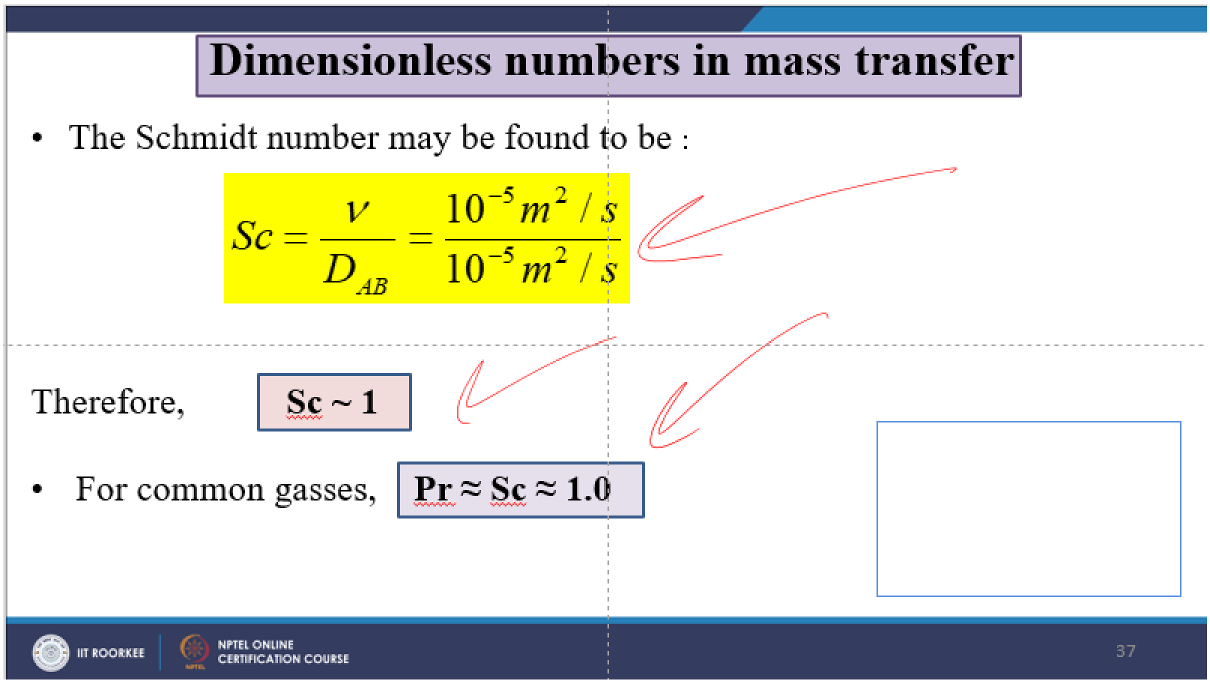




Sherwood number

$Sh = \frac{k_C d.p_{BLM}}{D_{AB}P_t} = \frac{(10^{-2}m/s)\times(2\times10^{-2}m)}{10^{-5}m^2/s}$ therefore, Sh=20

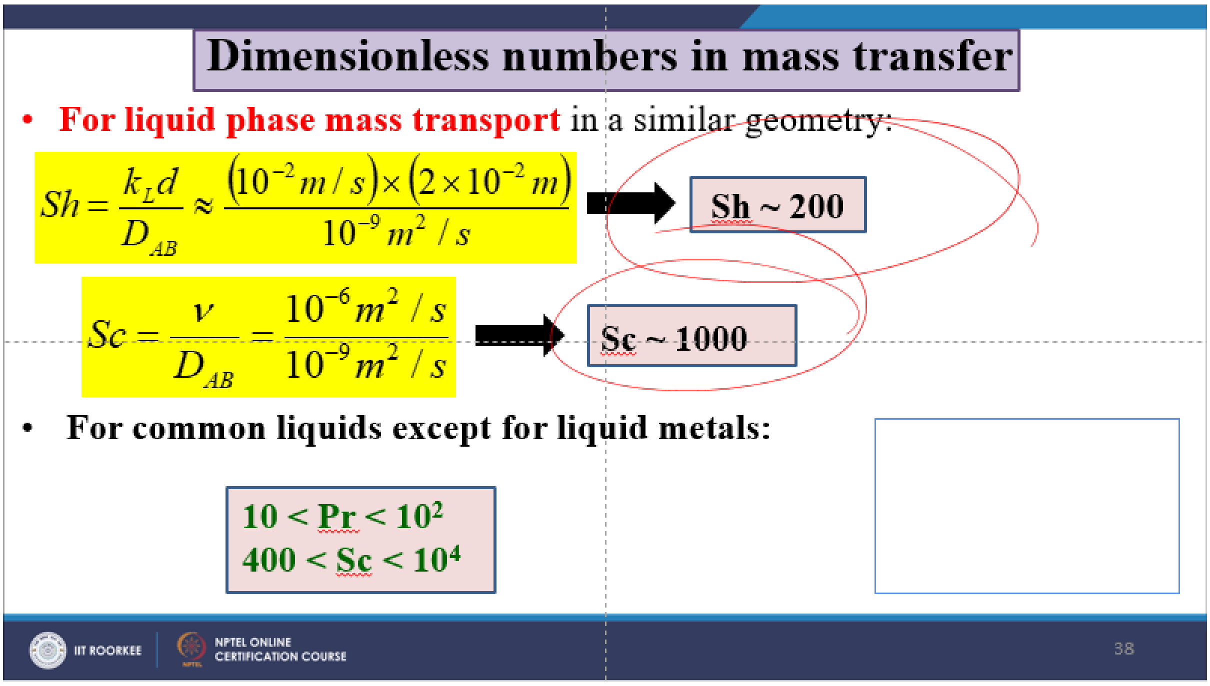
Now, Schmidt number also represents the relative order of magnitude of the thickness of concentration boundary layer in comparison with that of velocity boundary layer. Now, taking the case of gas phase mass transfer for flow past a sphere 2 centimeter in a diameter of a low partial pressure of the solute. So, p BLM over p t is almost equal to 1, then the Sherwood number can be represented as k c dt p BLM over D AB p t and if put the numerical value then it comes out to be nearly 20. Now, the Schmidt number may be found to be like this and therefore, if we say that Schmidt number is almost equal to 1, so for common gases the Prandtl number is almost equal to the Schmidt number which is representing 1.



The Schmidt number

$Sc = \frac{\nu}{D_{AB}} = \frac{10^{-5} m^2/s}{10^{-5} m^2/s}$ therefore Sc-1.

Now, for liquid phase mass transport system in a similar geometry the Sherwood number can be represented as k l d over D AB that is almost equal to 10 to the power minus 2 into 2 into 10 to the power minus 2 over 10 to the power minus 9 and this is the Sherwood number is almost 200.

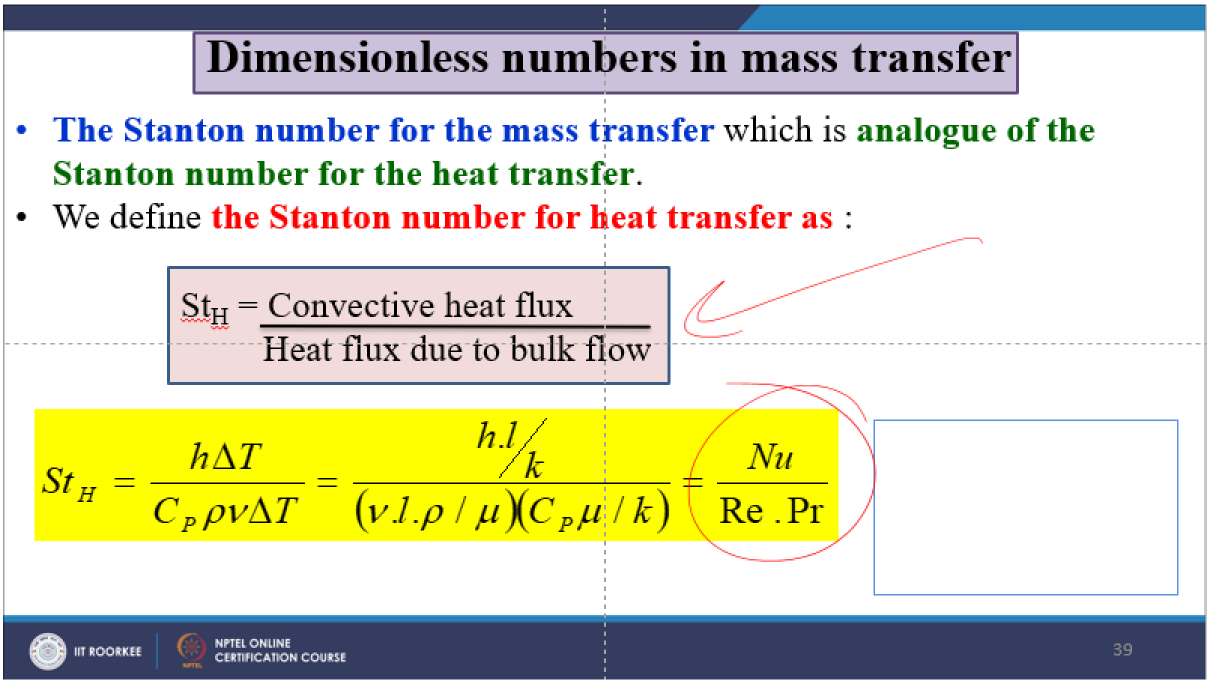


For liquid phase mass transport

$$Sh = \frac{k_L d}{D_{AB}} \approx \frac{(10^{-2} m/s)\times(2\times10^{-2} m)}{10^{-9} m^2/s} \text{ for } \mathbf{Sh \sim 200}$$

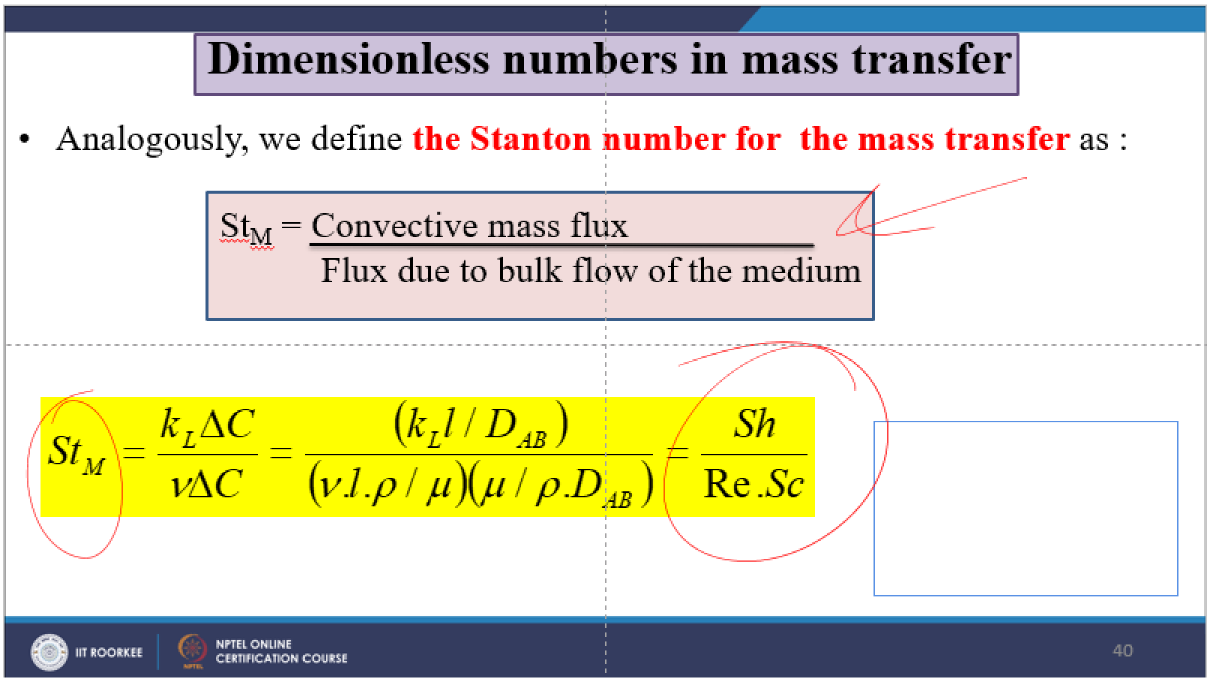
$$Sc = \frac{\nu}{D_{AB}} = \frac{10^{-6} m^2/s}{10^{-9} m^2/s} \text{ for Sc- 1000}$$

Now, if we put or if we compare with the Schmidt number this is comes out to be nearly 1000. So, for common liquid except for the liquid metals the Prandtl number is in between 10 to 10 to 10 to 10 square and Schmidt number is between 400 to 10 to the power 4. The Stanton number for the mass transfer which is analogous of the Stanton number of for the heat transfer. Now, we define the Stanton number for the heat transfer is the convective heat flux over heat flux due to the bulk flow which can be represented as Nusselt number over Reynolds number and Prandtl number.



$$St_H = \frac{h\Delta T}{C_P \rho v \Delta T} = \frac{h.l/k}{(v.l.\rho/\mu)(C_P\mu/k)} = \frac{Nu}{\mathrm{Re.\,Pr}}$$

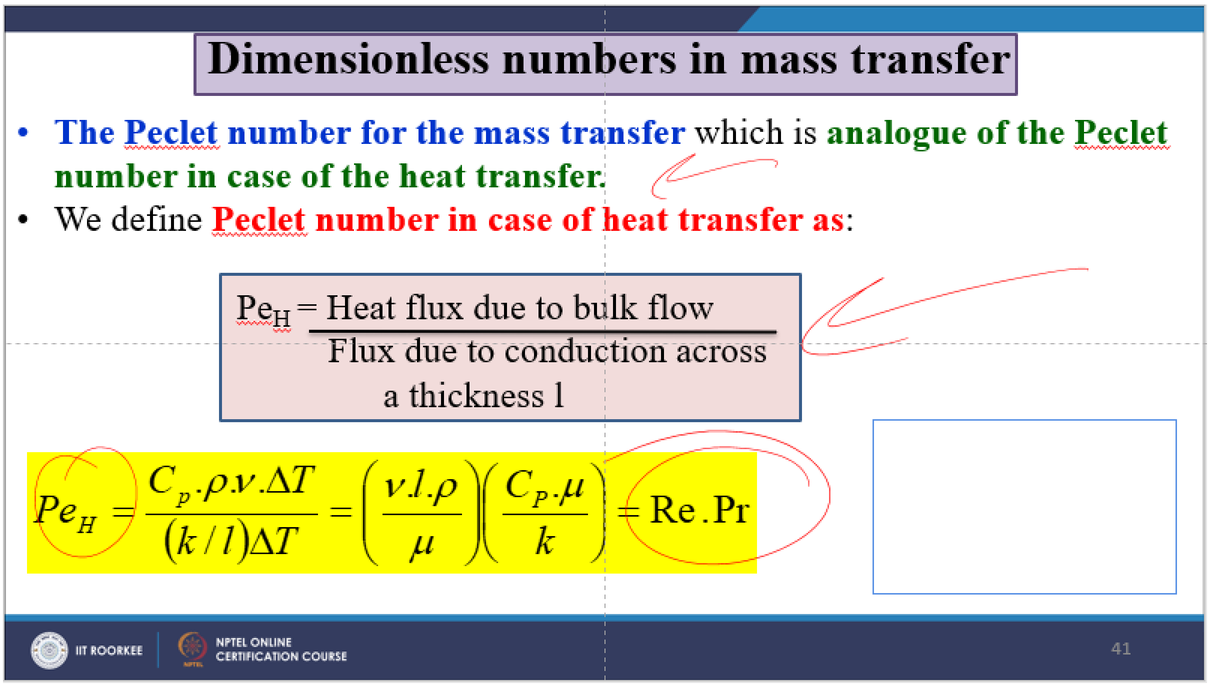
Now analogously we define the Stanton number for the mass transfer as convective mass flux over flux due to bulk flow of the medium and then it can be represented as a Sherwood number over Reynolds number and Schmidt number.

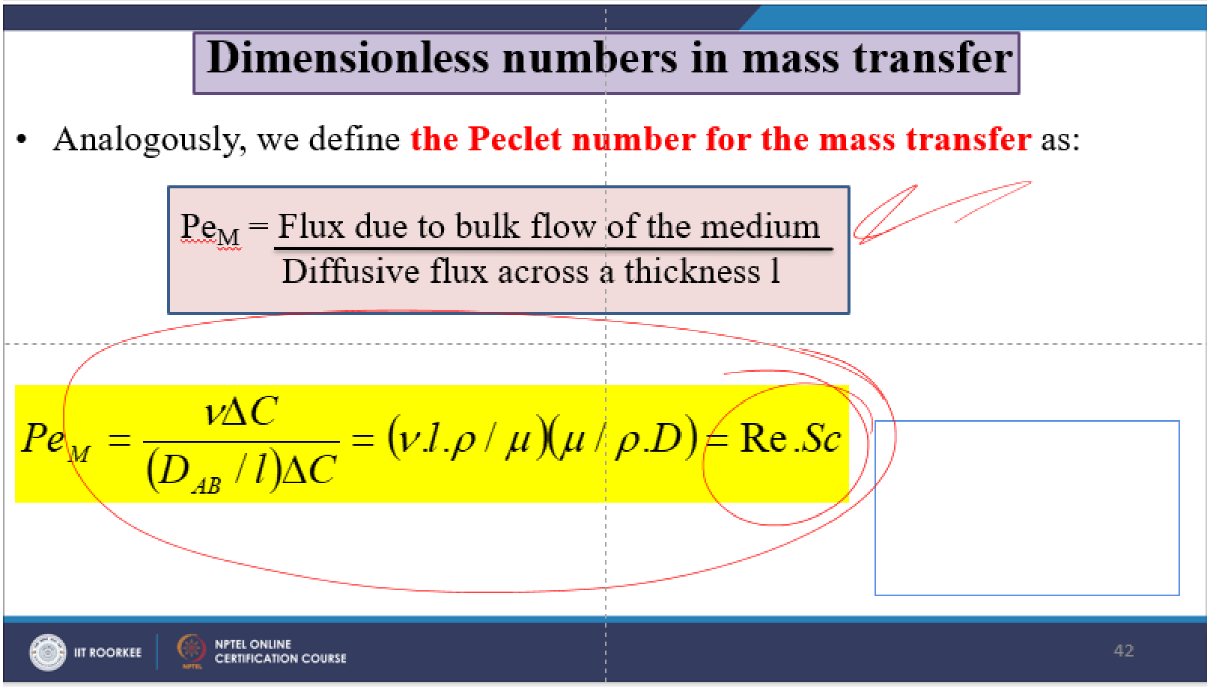


$$St_M = \frac{k_L \Delta C}{v \Delta C} = \frac{(k_L l / D_{AB})}{(v.l.\rho/\mu)(\mu/\rho.D_{AB})} = \frac{Sh}{\text{Re}.Sc}$$

The Peclet number for the mass transfer which is analogous of the Peclet number in case of heat transfer and we define the heat transfer Peclet number as a heat flux due to the bulk flow over the flux due to conduction across a thickness L.

$$Pe_H = \frac{C_p.\rho.v.\Delta T}{(k/l)\Delta T} = \left(\frac{v.l.\rho}{\mu}\right)\left(\frac{C_P.\mu}{k}\right) = \text{Re}.\text{Pr}$$





$$Pe_M = \frac{v\Delta C}{(D_{AB}/l)\Delta C} = (v.l.\rho/\mu)(\mu/\rho.D) = \mathrm{Re}.Sc$$

So, the Peclet number can be given as Reynolds number into Prandtl number and as per this particular analogy the Peclet number for the mass transfer can be defined as the Peclet number is equal to flux due to bulk flow of the medium over the diffusivity diffusive flux across the thickness. So, if we represent this in terms of the Peclet number this can be given as the multiplication of the Reynolds number over into Schmidt number.

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So, dear friends in this particular segment we discussed about the mass transfer operation and we discussed about the various dimensionless numbers which are useful for this particular segment. For your convenience we have been listed couple of references; you can utilize those as per your requirement. Thank you very much.