Heat Transfer
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Lecture-17
Heat and Mass Transfer Coefficients

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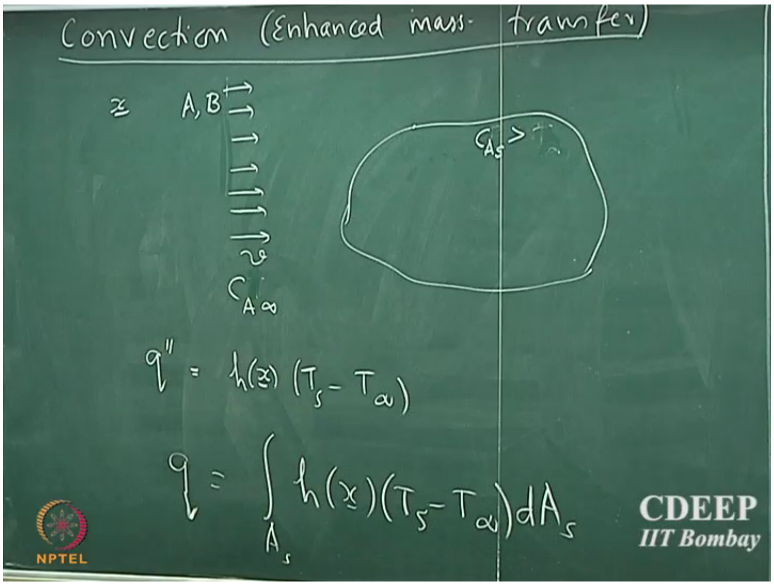

We initiated discussion on characterizing convection enhanced Heat Transfer. So, when we say conductive heat transfer, it really means that conduction enhances heat transfer and we will see in A short while how that is the case and why that is the case.

So, we considered a small an arbitrary shaped object and there is A fluid which is flowing pass this arbitrary shaped object let us say at velocity v and of the temperature is T infinity.

And let us say that we assumed that the temperature of the surface is maintained at T s. So, note that these 2 are measurable quantities remember that all through this course. So, far we have been talking about like you must always have something called measurable quantities you must compare with measurable quantities. So, the temperature of the surface and the temperature of the fluid which is flowing pass the object these 2 are measurable quantities.

So, you would like to express and you would like to detect the heat transport coefficient etcetera everything in terms of these 2 measurable quantities. So, that is why. So, the supposing you take the local flux of heat transport q double prime at any location let us say. So, that is given by h if this the local heat transport coefficient.

And, If x vector is the position vector. So, that is now 3 dimensional coordinates with position vector. So, naturally x is going to be A function of the position it depends on where you evaluate the heat transfer where you want to find the flux and that multiplied by T s minus T infinity if I assume that T s is greater than T infinity and we said that we can find total flux by simply taking an integral over the whole surface d A s. So, now, if we introduce A definition. So, note that it is A definition if we introduce A definition of average heat transport coefficient.

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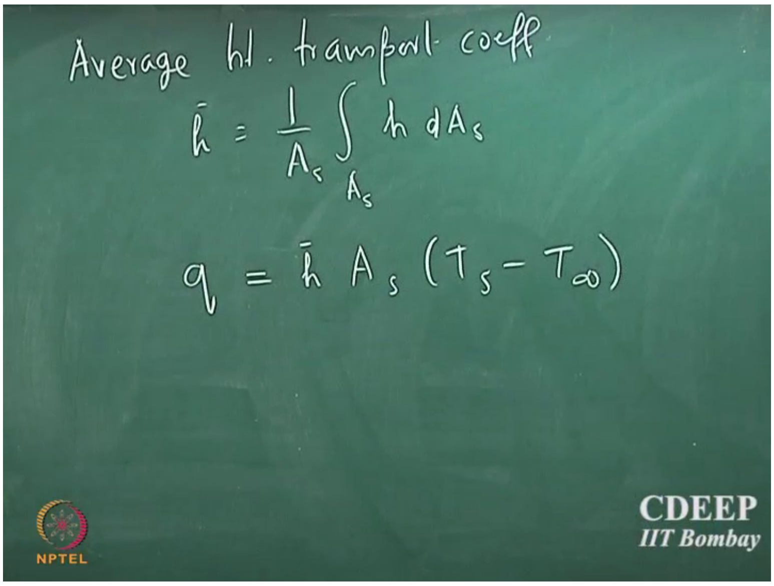

If I introduce the definition of average heat transport as 1 by A s. So, that is the A cross sectional or the area average of the local heat transport coefficient that is the definition. So, if we introduce this definition then we can write the overall net heat transfer rate is simply given by h bar into A s into T s minus T infinity.

So, when we really talk about Newton's law of cooling in the earlier framework and we discussed conduction we really meant it is the average heat transport coefficient we assume that it does not change. So, it is the average that we are looking at. So, in principle heat transport coefficient can be A function of position it is A function of geometry it is A function of the flow properties etcetera alright. So, let us turn back to mass transport.

A similar scenario in mass transport would be yes. So, if the concentration of some species is C A s and if the bulk species concentration is C A infinity the framework is slightly different in mass transport all though the process is exactly the same. So, supposing you have species A and species B both of them it is A mixture which is flowing together, and let us say that only species A is diffusing out species A is transported from this surface to the fluid.

So, the diffusion process would be later we can assume that B is in excess we can assume that point species B is in excess and we could assume that equimolar counter diffusion and therefore, what we are really looking at is transport of species A to the Bulk fluid outside. So, the what will be the net what will be the mass transport flux.

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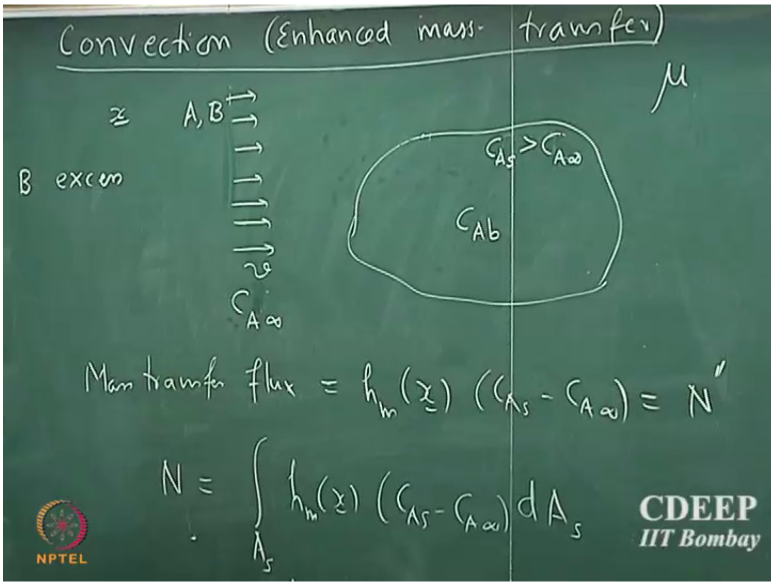

What will be the flux at any location if I assume that C A s is greater than C A infinity, what will be the mass transfer flux. So, note that heat and mass transport are similar right. So, you have some mass transport coefficient which is again A function of position multiplied by C A s minus C A infinity, I call this n double prime N is the symbol I use for mass transport rate and N double prime is the flux.

So, therefore, the net mass transport rate is given by Integral over the whole surface. So, what is C A s is it A measurable quantity remember that when we discussed heat transport we said that T s and T infinity are measurable quantities is C A s A measurable quantity supposing you have an interface right. So, this is an interface between 2 different phases this is A let us say solid phase or A fluid phase and this is A gas phase yeah what is measurable.

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Where?

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So, node fraction of A in both of the phase's supersizing I call this as C A bulk. So, that is the bulk concentration in that phase and C A infinity is the bulk concentration in the gas phase what is C A s.

Student: (Refer Time: 07:00).

Will that be same?

Student: (Refer Time: 07:16).

So, what will it be how do we find C A s is it A measurable quantity.

Student: (Refer Time: 07:23).

It is A concentration at the wall. So, how do we find let us assume that it is A well-mixed system inside here the bulk concentration is the same everywhere is C A s still A measurable quantity remember some of the concept you have learnt in thermodynamics and public transport also.

Student: (Refer Time: 07:53).

So, what is the balance that you would write at every location for this problem?

Student: (Refer Time: 08:01).

Excuse me.

Student: (Refer Time: 08:10).

Well not really what matches here is not the exact mass transport rate with respect to bulk concentration and the mass transport rate outside that is not the conserved property, what is the conserved property here have you heard chemical potential. So, you have heard chemical potential right.

So, what you have to match at the boundary is actually equilibrium between the species, which is present in the gas phase and the species which is present in the bulk space. So, the correct way to do is so, at the interface there will be an equilibrium there will be an equilibrium between the 2 phases.

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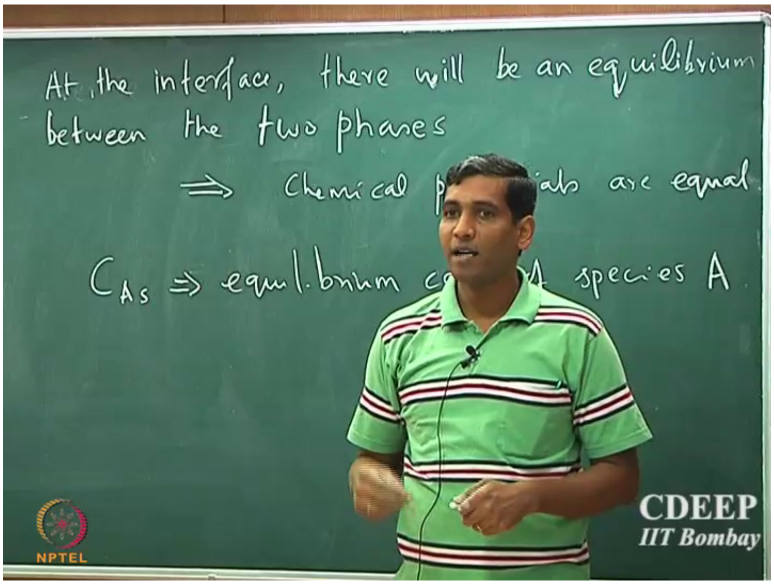

So, that which means that A chemical potential in the gas phase should be equal to the chemical potential in the liquid phase or A solid phase right. So, the chemical potentials are equal.

So, at the interface the chemical potentials are equal and therefore, if you actually balance the chemical potential you will find that C A s is actually not the bulk concentration it is actually the equilibrium concentration. So, C A s is the equilibrium concentration of species A. Now what it means is that unlike in test in the case of heat transport where you supply heat the material is going to have A certain capacity. So, it is going to take energy and the temperature is going to increase that is not the case with mass transport so you always have the issue of what is called saturation.

There is only A certain amount of solubility of A particular species in A given medium right, you cannot add more species to it if you are above the solubility limit. So, unlike in mass heat transport A system does not have infinite capacity to take up mass there is an upper limit and that upper limit the correct way to balance the upper limit is actually by equating the chemical potential.

So, what equilibrium concentration really means is that what would be that concentration based on the solubility of these species in these 2 phases, what will be the equilibrium concentration if the chemical potential has to match that is what that interface concentration is. So, that is it is intrusively A measurable quantity, if you know the bulk concentrations of 2 phases and if you A 1 can actually.

Find out what is the chemical potential we know the relationship from thermodynamics and we should be able to find out what is the interface concentration. So, it is in principle A measurable quantity, but not A direct measurable property. So, the direct measurable property are the bulk concentration of the species in the solid or the fluid phase and the bulk concentration in the gas phase that is C A infinity.

Student: (Refer Time: 12:26).

Right if you assume in heat transport case the question is will there not be A temperature gradient. So, note that I said it is A well-mixed system. So, C A b is the bulk concentration everywhere, similarly if you assume that it is A well-mixed system where the temperature is uniform it is A same scenario. The only difference is that there the system actually can take more energy and it will lead to increase in the temperature that is not the case with the liquids that is not the case with mass transport there is an upper limit on how much you can pump.

And that is based on the solubility of that species in that medium, unlike in heat transport where you supply energy the energy is going to be stored and you increase the temperature that is not the case here. So, it is not that you can infinitely increase the temperature I mean it does not happen really in heat transport, but in principle you can infinitely increase the temperature there will be change of phase etcetera will not be in which that, but in principle it can take energy more and more, but that is not the case with the with respect to the mass transport. If you assume that phases do not change then in heat transport you can continue to supply heat till there is A phase change after that the process is slightly different.

So, let, but that is not the case with mass transport. So, there is no such limit us to phase change, but there is an upper limit called solubility limit. So, C A s is essentially obtained by equating the chemical potentials and that is the equilibrium concentration at the interface.

So, right now what we will do for rest of the convection topic is that we will assume that we know how to measure the interface concentration C A s and we will assume that the concentration gradient is C A s minus C A infinity. In fact, that is the correct concentration gradient ok.

Student: (Refer Time: 14:17).

Excuse me.

Student: (Refer Time: 14:21).

We are not talking about heat transport we are talking about mass transport we need concentration gradient if there is no concentration gradient there is no mass transport. The only question is what is the correct gradient? When it comes to heat transport we said that the concentration the temperature gradient is the difference between the bulk temperature in that phase if it is well mixed and the bulk temperature in the fluid outside that is not the case when it comes to mass transport. The interface concentration the equilibrium concentration can actually be different from the bulk concentration here because equilibrium concentration will specify based on the solubility.

What is the maximum that it can take? So, it is very important to understand this distinction that here we are not looking at bulk concentration whereas; in heat transport can actually specify bulk temperature as one of the temperatures in the temperature gradient.

Student: (Refer Time: 15:19).

We are going to talk about, but note there is A boundary layer is in the fluid phase not in the solid.

Student: (Refer Time: 15:45).

That we are going to see. So, here we are talking only about what is happening inside this medium, when you talk about boundary layer boundary layer is actually outside that media which is actually in the fluid phase.

Student: (Refer Time: 15:56).

We are going to talk about that because boundary layer concept is for the fluid phase not for the solid phase. Now we are only trying to define what should be the reference temperature inside this phase and what should be the reference concentration. In this phase if you assume that the system is unmixed if you assume that there are no gradients inside then the bulk temperature is the reference temperature for this particular phase and the equilibrium concentration is the reference concentration not the bulk concentration.

Student: (Refer Time: 16:25).

It depends on the size of the system, supposing if you use A remember the lumped capacitance method we talked about if you can maintain your dimensions such that you can maintain A uniform temperature and uniform concentration why not it is possible very much possible. So, similarly we can define what is called the average mass transport coefficient.

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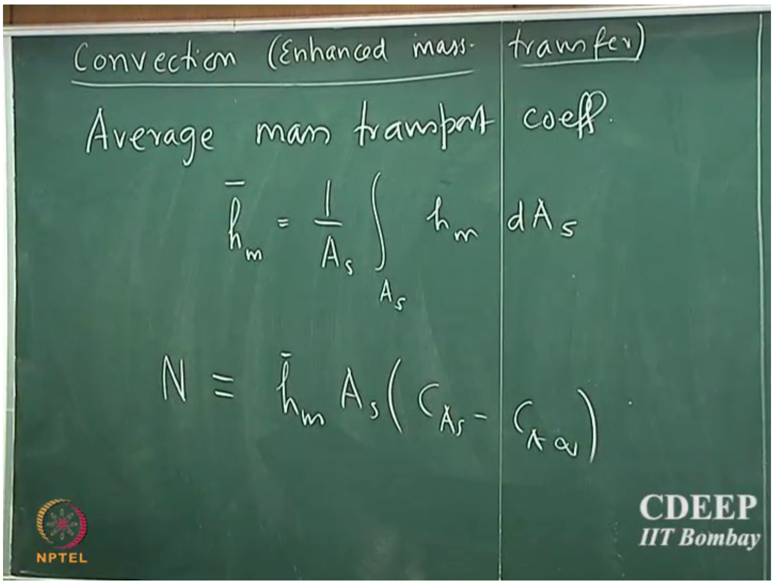

You can define average mass transport coefficient. So, h m bar which is the average mass transport coefficient average toward the wholes of area. So, that will be 1 by A s integral over the surface into d A s. So, using the average mass transport coefficient we can now define the net mass transport as h m bar into A s A infinity. So, that is the net mass transport rate based on the average mass transport coefficient alright. So, supposing if you take A flat plane.

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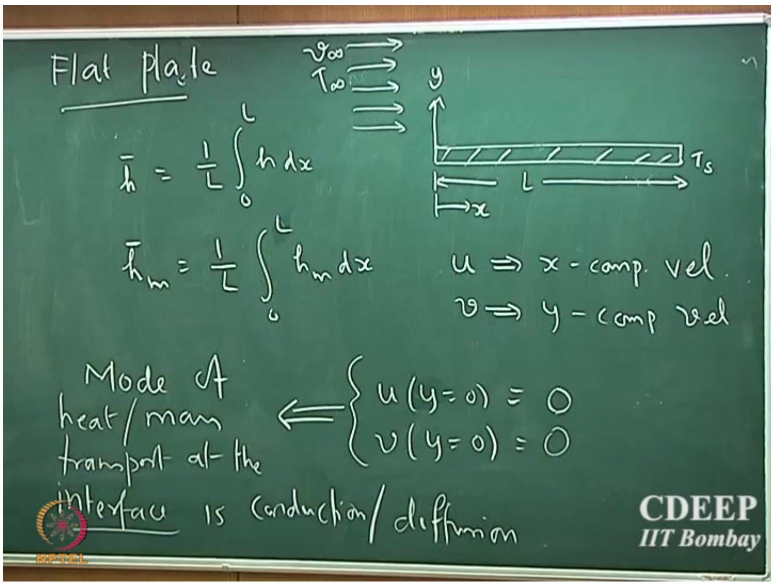

Suppose we take A flat plane. So, we have A flat plane and let us say it is maintained at some temperature T s and we have fluid flowing pass this flat plane and let us say velocity v and T infinity. So, the average heat transport coefficient h bar will be 1 by L integral between 0 to L. So, if the length of the plate is L and if this distance is x this direction x might be h time d x. So, I assume that it is A uniform cross section uniform length in the other direction. So, the other plane is infinitely long. So, the heat transport coefficient essentially averaged over the length and similarly 1 can write A mass transport coefficient which will be 1 by L 0 to L h m times d x.

So, that is the average heat transport and average mass transport for flow passed on flat plane. So, now, comes the question of what happens inside the fluid phase. So, that is the whole aspect that we going to discuss how to find out the heat transport coefficient in this phase. So, that is what we are going to find out. So, whenever there is A fluid which is flowing past an object. So, you must have studied in your fluid mechanics course there it is going to be A boundary layer right. So, as soon as the fluid reaches the (Refer Time: 19:41) starts seeing the flat plate what will be the velocity of fluid at the boundary at the interface the velocity is 0 right. So, suddenly so supposing if I call this as y direction and this is the x direction.

And suppose I use I specify that your v infinity is the. So, velocity of the free stream fluid that is before the fluid actually sees the flat plate what is the velocity of the fluid and if I assume that it is A flat profile that is not A bad assumption to make. Then if I say u is the x component velocity and v is the y component velocity, what is u and v at y equal to 0 u equal to u at y equal to 0, A 0 right because it is an interface where the flat plate is not moving it is A solid plate. So, the fluid is now in contact with the flat plate at that location.

And so suddenly the fluid comes to rest, because there is friction. So, the fluid is not allowed to slide pass the flat plate and therefore, the fluid particles will come to rest. So, the velocity x component velocity at y is equal to 0 is 0. So, the fluid is not made to move in the other direction what about the y component velocity v at y equal to 0 that is also 0. So, fluid is rest fluid is at rest. So, when fluid is resting it means that all the component is 0. So, u and v the x component and the y component velocity at y equal to 0 always 0.

Because of no slip boundary condition right. So, there is no slip the fluid does not slip along the flat plate and therefore, the velocity is 0. So, that has an important implication in heat and mass transport. So, what is the mechanism of heat transport at the boundary what is the mode of heat transport it is the 3 mode conduction convection and radiation right.

So, because the velocity is 0 at the interface the actual mode of heat transport from 1 phase to another is actually conduction. So, this has A very very important implication that the mode of heat transport heat or mass transport at the interface very important at the interface is conduction or diffusion. So, therefore, the mode of heat transport or A mass transport is essentially conduction or diffusion. So, this observation actually simplifies A lot of things for us. So, how does it simplify.