Heat Transfer
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Lecture - 41
Condensation: I

So, we looked at boiling in the last lecture today we are going to move to condensation .

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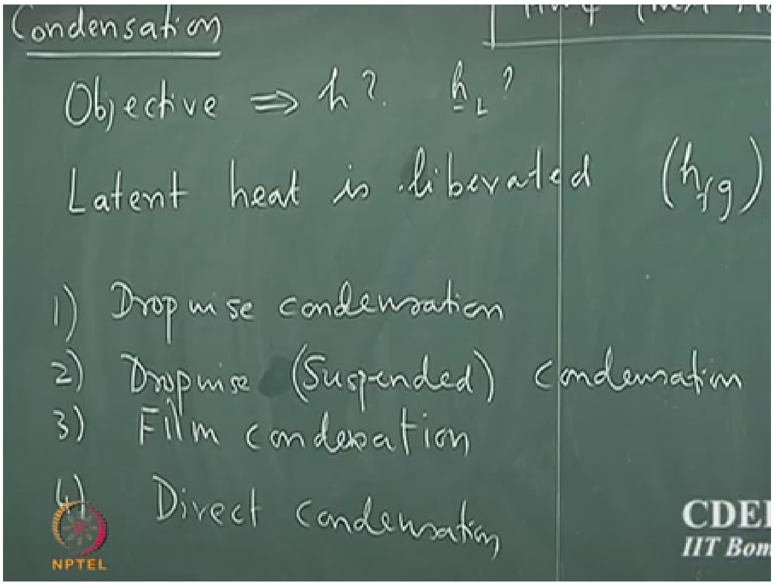

So, what we going to see today's lecture is; going to look at how to characterize condensation process and once again the objectivity is same to find out the heat transport coefficient. What is h and what is average heat transport coefficient? So, that is what we are going to see. So, what happens during condensation we looked at boiling where heat is supplied to the fluid and the fluid is converted from the liquid to the vapor phase?

So, there is a phase change that is occurring, because of heat transport from the wall or a solid to the fluid, what happens in condensation is exactly the opposite process where the fluid is going from vapor to the liquid phase and while doing that it is also liberating heat which is taken up by the surface or a wall which is present next to it ok. So, it is the reverse process where the latent heat is liberated.

So, during condensation the latent heat which is released by the fluid and in boiling it exactly the reverse it is the heat that is taken up by the fluid in order to go from a lower energy to a higher energy state all right.

So now, so there are four types of. So, once again; obviously, the latent heat plays a role here. So, h f g which is the latent heat of the fluid plays an important role. So, there are four types of condensation ok. So, one is the drop wise drop wise condensation and then, have drop wise suspended condensation and then in the third one is you have film condensation and the forth process is direct condensation ok.

So, these are the four types of condensation process. So, the first one drop wise condensation what happens is that; in the drop wise condensation process.

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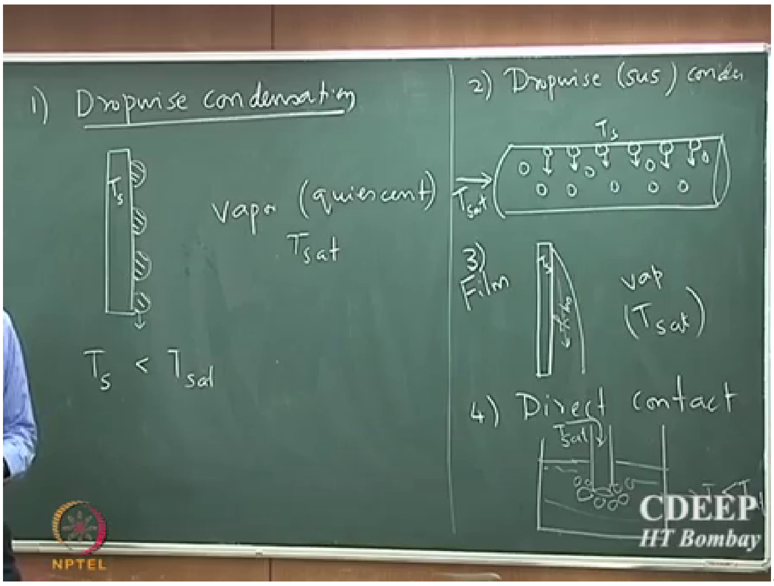

So, supposing if there is a wall which is located and there is let us say vapor which is present. And let us assume that quiescent vapor it means that the vapors are not moving, because stationary and let us say that the vapor is at some saturation temperatures which is the condensation point and the temperature of the plate is T s. So, T s should be less or greater than T sat it should be less than T sat.

Because vapor is now going to loss heat it is going to form liquid and that heat is being taken up by the wall ok. So, now, what happens is you have drops which are formed along this surface ok? So, these are drops which nucleated during the condensation process. So, when it gets nucleated they slowly drop down one by one and then the liquid is collected. So, they slide along the surface of the wall and then the liquid is collected. So, the condensate is collected that is the drop wise condensation process. So, now, if I look at the if I look at the suspended drop wise suspended condensation.

Suspended condensation process; so suppose if I take a tube suppose if I take a tube this is a fairly common drop wise suspended drop wise condensation it is fairly common and several heat transport equipments. So, suppose if I take a tube and the surface of the tube is maintained at temperature T s and there is vapor which is flowing through this tube at let us say the saturate temperature T sat ok. Now, the bubbles will form along the curved surface of the tube, and then note that this is a horizontal tube right. So, they will detach and then they will drop into the vapor there will all detach and so, now, you will start having these drops which are suspended inside the vapor.

So, this is the drop wise suspended condensation process and then the third one third one is where we have film condensation process. So, suppose I have a a wall which is at a let us say temperature T s, and there is vapor which is maintained let us say at T sat, at the saturation temperature. Now the condensation rate will be such that that there will be a film which is form here a liquid film which is form here and the liquid film will start moving and then the condensate is the collected at the bottom of the wall ok. So, that is the third one which is the film condensation process. So, what we are going to see in today's lecture is going to characterize this film condensation process ok.

Now, the fourth one is the direct condensation direct contact direct contact condensation process and this mode of condensation; occurs when you have contact between two different fluids at different temperature ok. So, now, suppose I have a container a simple way to visualize, suppose I have a container and I have a fluid let us say. So, I have a tube here I have a fluid which is maintained at yes now I m going to pass gas through this tube and this is at T sat; that is a vapor which is at T sat I am going to pass this gas through this tube. Basically, I am going to bubble the vapor to this liquid now what happens this?

This is at a temperature which is smaller than T sat that smaller than T sat and therefore, as the bubbles comes inside moment they come in and contact with the liquid which is at a significantly of lower than the saturation temperature then there immediately going to from bubbles here fine. So, that is called the direct contact condensation, where two liquid is a different temperatures one of them is going to condense, because the other liquid is at a significantly at a lower temperature ok. So, this is what a called a direct contact condensation. So, what we are going to see for the rest of today's lecture is going we are going to characterize the film condensation process this is difference here the drop wise the drop are forming at a solid surface here the drops are actually forming in bulb. So, film is when you have significant.

Drops that is forming the condensation rate is significantly higher; what you will have is actually it is start with a bubble and drop wise and then it will actually transition to film, because the condensation rate is significantly higher before the drops fall.

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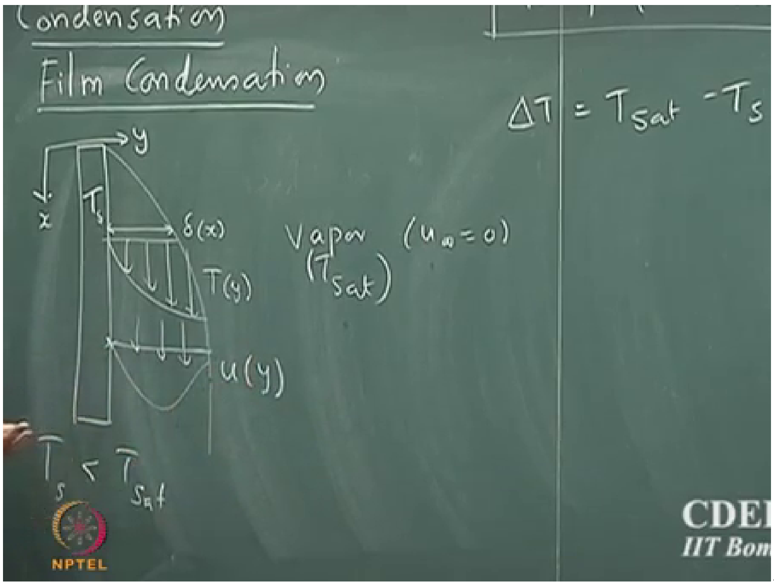

There will be more amount of liquid which will come and deposit on the surface and so, what you will have is a continues flow stream of liquid which is actually a film conversation process ok. So, now, I have a film here and that is my bound layer thickness, delta x and I have a vapor here, which is at T sat and this at a temperature T s and we assume that T s is smaller than T sat ok.

So, what is the driving force or condensation; this is the temperature gradient right. So, delta T the driving force is T sat minus T s. So, that is the driving force for condensation. Now, so T s is small than t sat. So, we can intuitively guess what is going to be the temperature profile? So, that is going to be the temperature profile. So, that T as a function of y ok; what will be the velocity profile; same different. So, remember that vapor is at a at rest it will be a ok.

So, so you would accept that the u of y you should have a maxima, because vapor is at rest ok. So, you accepted to have a maxima at the middle. So, if you look at your text book there is a mistake in this particular profile that they have drawn. So, so you would accept that there is maxima at some were in the boundary layer. So, the vapor is at rest, because it is complete rest and.

So, you have u infinity is 0 ok. So, now, so now I can write momentum balance. So, all the usual thing that you have been doing in this course. So, the question is why should there be a maxima right? So, remember that the velocity of the fluid at the wall, what is the velocity of the fluid at the wall; it is 0; because it is a it is a no slip condition and so it has to be 0 the fluid comes to rest and the fluid is going to be.

At rest because the vapor is not moving it is a quiescent fluid. So, vapor is moving. So, the fluid is now moving in the film. So, it is bounded between two locations which have 0 velocities. So, there has to be maxima in between all right.

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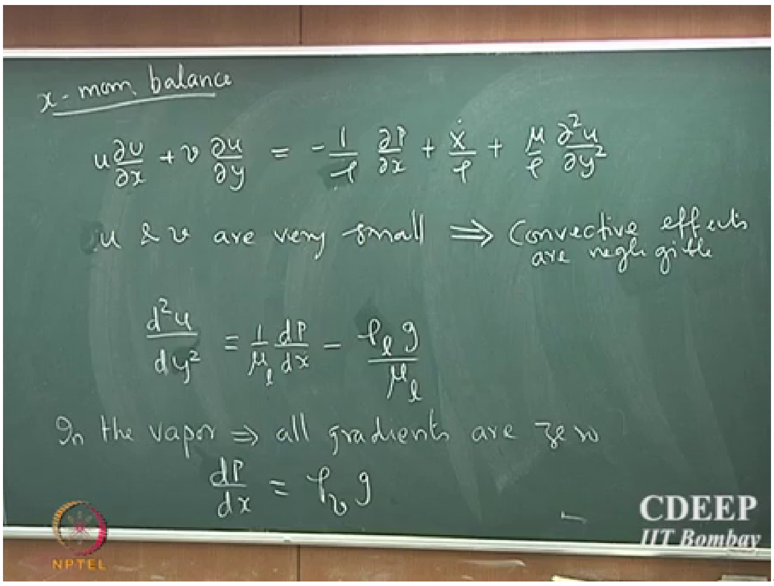

So, now we can write an x momentum balance. So, u d u by d x plus v d u by d y, that is equal to minus 1 by mu oops 1 by rho d p by d x plus x dot by rho. So, note that I am using a plus sign, because I have dou if my x direction is now in the positive gravity direction plus mu by rho d square u by d y square ok.

Now, we make an assumption here one could actually do without doing the assumption, but you will not get some inside that you will get. So, the first assumption we make is that the u and v are very small and that is not a bad assumption actually. So, the velocity of the fluid inside the boundary layer is very small and therefore, therefore, the convective effect; the convective effects are negligible. So, now,. So, if the convective effects are negligible we can neglect the left hand side of this momentum balance ok.

So, therefore, we can write the momentum balance is d square u by d y square that is equal to d p by d x 1 by mu; that is mu of liquid because here the momentum balance is in the boundary layer. So, we are looking at the liquid system minus rho, liquid into gravity divided by mu liquid ok. So, now, we said that the vapor is at rest right. So, vapor is at rest the velocity is 0 and also all the gradients are 0 all gradients are 0. So, therefore, outside the boundary layer.

The momentum balance will be d p by d x that is equal to rho vapor into gravity ok. So, this is the same thing what we did with the natural convection before we just write the momentum boundary layer equations in the outside the boundary layer velocity is 0, all the gradients are 0, and therefore, the pressure gradients is going to be a simply given by rho vapor remember it is the density of vapor not the liquid density of vapor multiplied by gravity ok.

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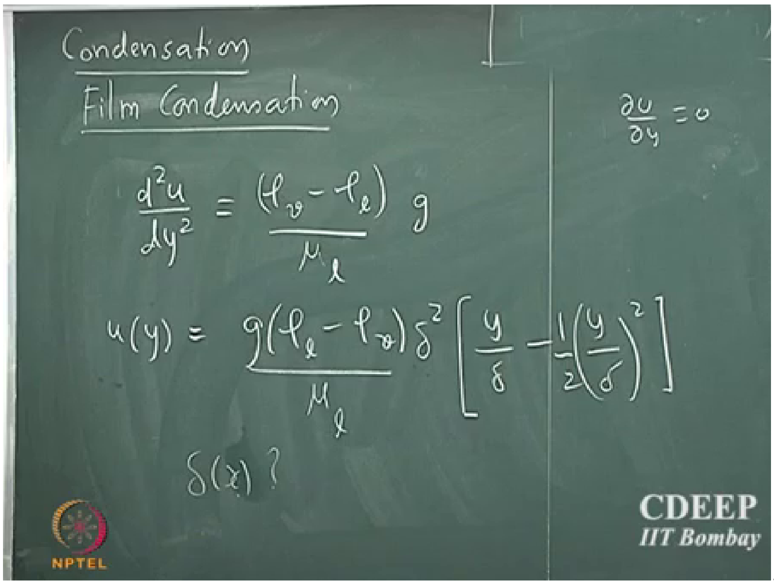

So, now if I plugging that quantity. So, I plugging that quantity. So, we have d square u by d y square that is equal to rho vapor minus rho liquid divided by mu liquid into gravity ok.

So, that provides the mechanism to find the x component velocity profiles inside the boundary layer ok. So, I can solve this equation u y, that is equal to g into rho l minus rho vapor divided by the viscosity of the liquid delta square delta minus half y by delta the whole square ok. So, that is the solution all right. So, now, do we know the velocity profile from this expression yes or no yes you do not know what delta is a still do not know what is the velocity profile. So, really the exercise here is to find out what is the boundary layer thickness?

So, we need to find out what is this delta? What is the boundary layer thickness at any location? So, until we found the boundary layer thickness the problem is not complete. We cannot find the velocity profile and. In fact, the same issue will continue when you write a temperature balance. So, how do we find this ok? So, there are two ways of doing this: one is you could use y tending to 0, you could also use d u by d y equal to 0 why? See you are solving only inside the boundary layer. So, it is a fixed boundary value problem you use similarity variable when you are having infinite boundary value problem.

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That is true. So, that is why see you have a definition for the boundary layer right because the vapor is at 0, this will be the correct boundary condition that you have to use and simply.

Because we are interested in solving the profile inside the boundary layer how we find the boundary layer thickness. So, if we know the boundary layer thickness we are done ok. So, now, so, this is a sort of a simultaneous heat and mask transport problem. So, remember that when the condensation process occurs there is a certain amount of condensate which is being collective right.

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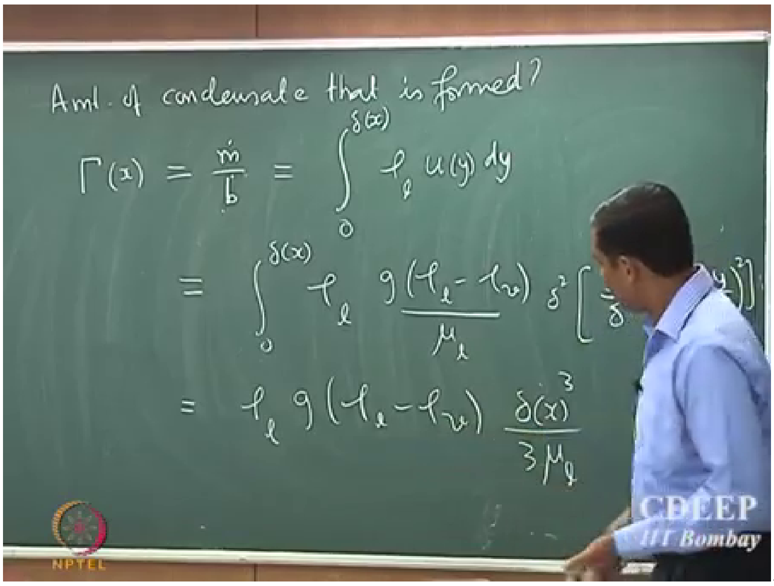

So, all the way not going to write mask transport equation, but what we are going to find is what is the total amount of condensate; without doing this we will not be able to solve this problem and the reason is. So, remember that and there is a condensation process which is occurring there is the latent heat is being lost by the vapor to form the condensate.

So, unless you know what are the total amount of condensate that is formed you will be not be able to relate the amount of latent heat, that is actually being liberated by the vapor in order to form the condensate, because the latent heat is liberated per unit mass of the vapor that is actually forming the condensate. So, therefore, it is important to find out, what is the amount of condensate; that is formed and that is how we are actually going to relate the boundary layer and the reason, why the that that works is the boundary layer thickness remember that the boundary layer con consist of the fluid which is the condensate which is formed.

So, therefore, if you want to know what is the boundary layer thickness you want to know what is the amount of fluid; or liquid which is present in that location. So, that is what defines your boundary layer thickness. So, therefore, we directly get to the question of what is the amount of condensation that is being formed ok. So, now, based on the velocity a supposing if I call gamma x.

As the amount of condensate at any location ok. So, that is given by m dot by. So, suppose if I have the thickness of my plate is b on the other side length of the plate. So, if m dot by b I am using b, because I want to consistent with the legend that is used in your text. So, m dot by b is the amount of condensate, that is actually formed rate of condensate formation per unit length which is outside the book and so, that will be integral zero to up to boundary layer thickness the density of the liquid multiplied by the local velocity into d y; that is not difficult we know how to do that. So plugging this 0 to delta x rho l into g rho v divided by mu l into delta square y by delta minus 1 by 2 y by delta.

The whole square into d 1 ok. So, we can integrate this the expression. So, that will turn out to the rho l into g rho v multiplied by delta x cube divided by 3 times mu l all I have done is I have just integrated between 0 and delta.