**Heat Transfer**
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**Lecture - 42**
**Condensation: II**

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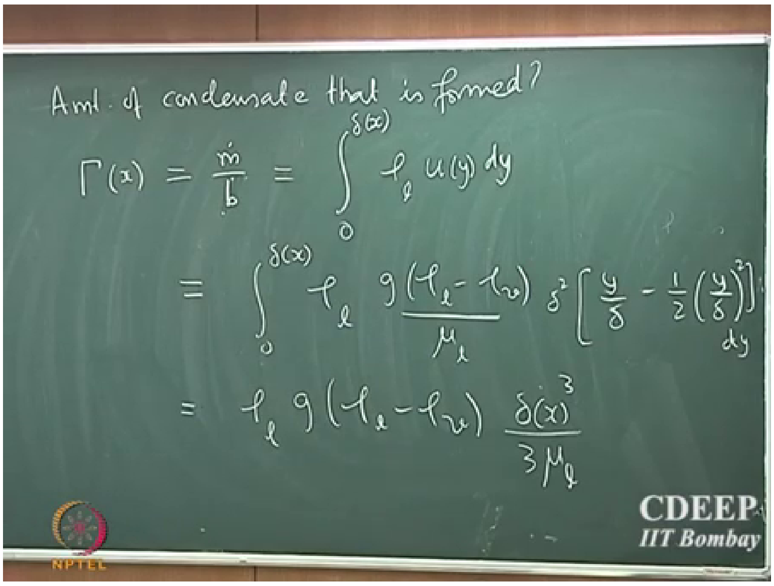


How do we relate the amount of condensate to latent heat? The amount of heat; so, we are going to write a simple heat balance. So, this is my wall (Refer Time: 00:26) film.

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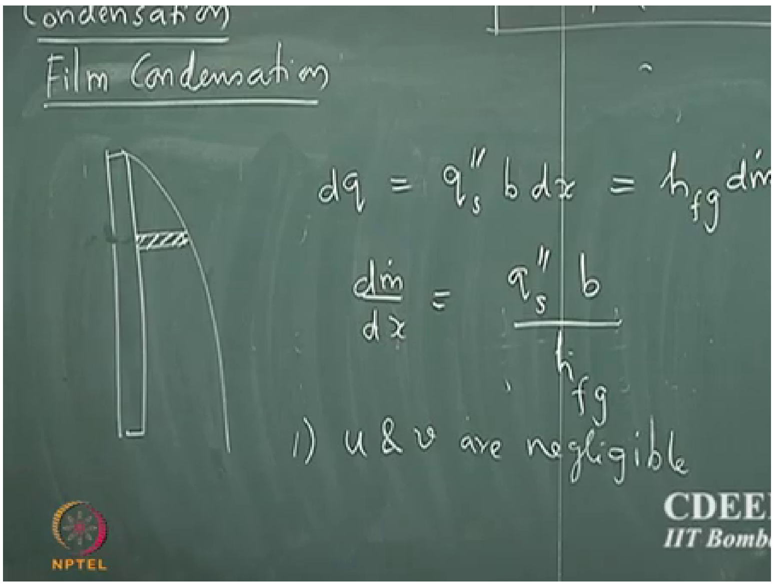

So, if I take a small location here ok. So, the amount of fluid which is present here depends upon the amount of heat that is actually transported from the vapor to the wall right. So, d q that is the rate at which the heat is transported from the vapor to the wall that should be equal to some flux of heat transport multiplied by b into d x; b is the length of the plate outside the (Refer Time: 01:00) and that should be equal to relatent heat multiplied by that is the rate of condensation differential rate of condensation multiplied by the latent heat of vaporization.

So, that tells me gives me a relationship between the flux and the mount of fluid that is condensate right. So, from here I can find out d m dot by d x is given by q s into b divided by h f g ok; what is q s q s double prime? How do you find that? So, it is really not a chicken egg problem; how do we find q s double prime ok? So, remember that we said that the u and v are negligible which means that the convection effects are ignored. So, if convection effects are ignored what is the primary mode of heat transport? Is only conduction; what is the flux for a 1 D system? It is k into q s double prime.

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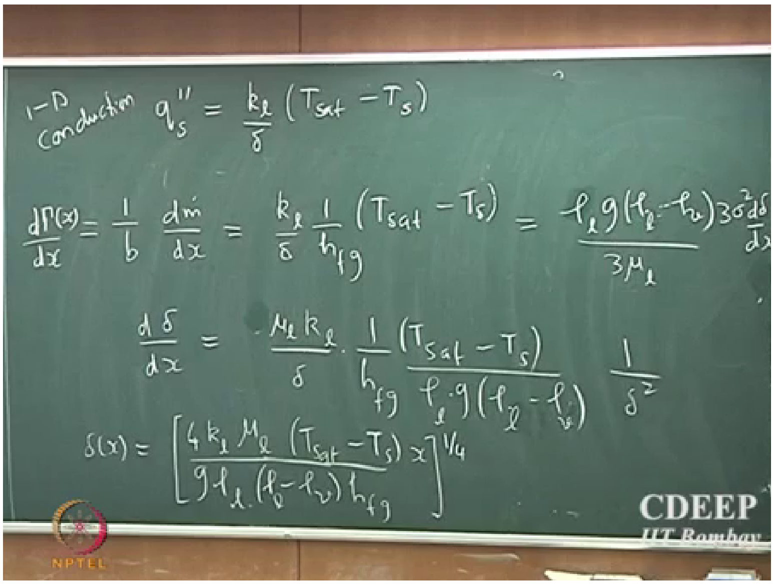


So, remember that now, it is a 1 D conduction problem ok. So, it is a fixed temperature the temperature of one end of the 1 D problem is T s and other end is T sat ok; q s is simply given by k liquid that is the conductivity of the liquid divided by delta; divided by the thickness of the 1 D slab right multiplied by T sat minus T s that is the flux of heat transport ok.

So, from here the conduction that we did the start of this course ok; so, now, if you plug that in we have 1 by b; d m dot by d x that should be equal to k l by delta, 1 by h f g into T sat minus T s ok. So, now, by writing heat balance and taking into account that it is a 1 D conduction problem. So, we have found a relationship between the condensate rate ok. So, m dot by b is the amount of condensate per unit length of that of the wall it is actually going outside this board right this is nothing, but d gamma x by d x that is 1 by b.

But we know the expression for the amount of condensate per unit length. So, if I substitute that here; so, that will be. So, that will be rho l g rho l minus rho v divided by 3 times mu l into 3 delta square d delta by d x ok. So, all I have done is I have differentiated the expression for the amount of condensate that we estimated using momentum balance. Remember short while ago we estimated the amount of condensate from momentum balance, I take the first differential and that is this expression ok. So, from here; so, now, I have got an expression for d delta by d x and so, that is given by 3 mu l mu l into k l divided by delta f g T sat minus T s divided by rho l; g rho v minus rho l.

The rho l; rho l minus rho so; so, now, we have got an expression for the bound layer thickness. So, we can integrate this expression and we will find the bound layer thickness and that will turn out to be 4 times k l mu l divided by.

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Did I make a mistake? Oops 3 delta square 1 over delta square thanks; I cancelled out this 3 thanks. So, that will be g time rho l; rho l minus rho v; h f g, T sat minus T s multiplied by x to the power of 1 by 4.

Ok. So, that is the expression for the down layer thickness. So, we have a question why are we so, concerned about bound layer thickness for this problem? We never worried about boundary layer thickness for any of the problem we looked at right, why are we so concerned? Why is it important for this problem ok?

But how do we find heat transport coefficient? We know the objective is to find heat transport coefficient; how do we find heat transport coefficient? We know the boundary layer thickness now what is the heat transport coefficient? It is there on the board it is k l over delta.

Fine what is the definition of heat transport coefficient?

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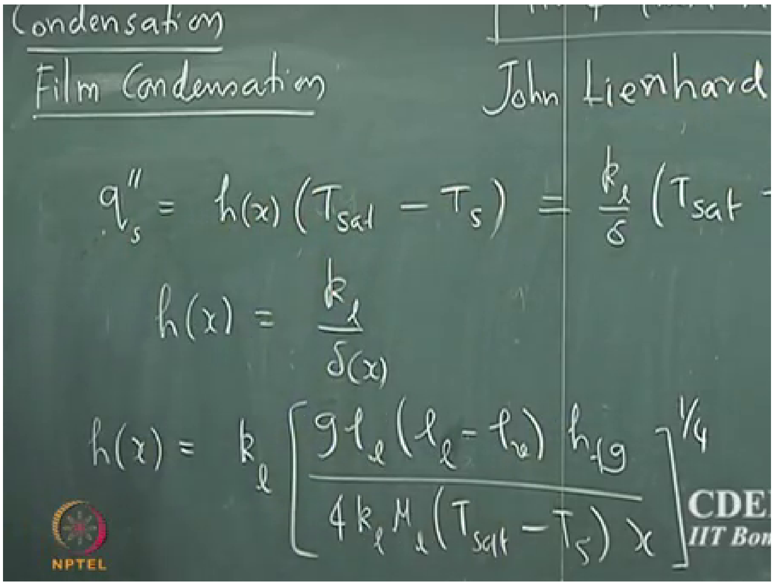


From Newton's law of cooling; He say that the net amount of heat the flux of heat that is transported is heat transport coefficient at that location multiplied by the temperature difference. So, that is the definition right and so, from because it is a 1 D conduction problem the flux is given by k l by delta into T sat minus T s. So, you could actually read out from here that the heat transport coefficient is nothing, but k l by delta. So, that is why we have been concerned about finding the boundary layer thickness ok; so if we know the boundary layer thickness we are done we have found the heat transport coefficient for the sum.

Ok. So, we know the boundary layer thickness; so, the expression for heat transport coefficient is given by k l into g; rho l, rho s, rho liquid, rho v divided by 4 k l, mu l, T sat minus T s into x to the power of 1 by 4 ok. So, this expression and some of the other expression we are going to see today is because of this very well known person called John Lienhard; he has made significant contribution to heat transport problem that he has booked to his name.

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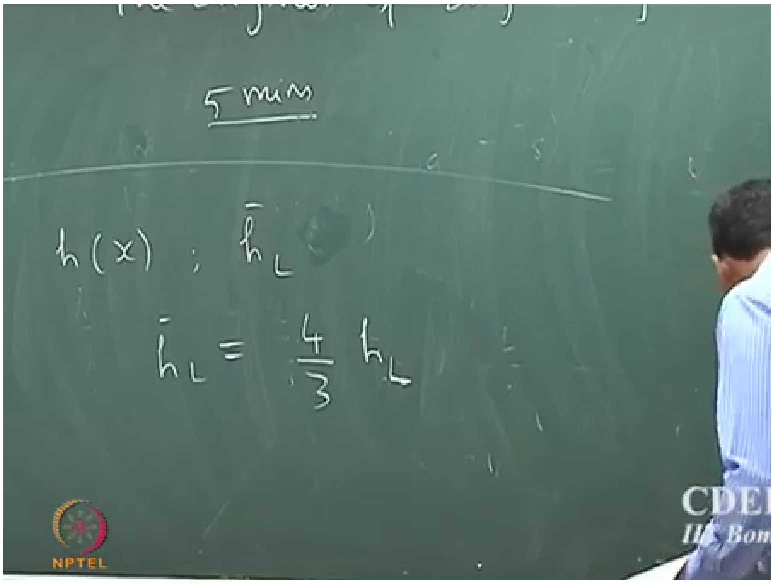


So, now, he said there are two objects one is the local heat transport coefficient and second one is the average heat transport coefficient ok. So, suppose is the length of the plate is L.

So, we want to find the average heat transport coefficient by now it is the almost trivial exercise you know what is the formula is; plug in the heat transport coefficient and you can find the average ok. So, the average turns out to be turns out to be 4 by 3 h of x. Also, now, I can define Nusselt number h of L thanks h of L ok. So, now, I can define Nusselt number.

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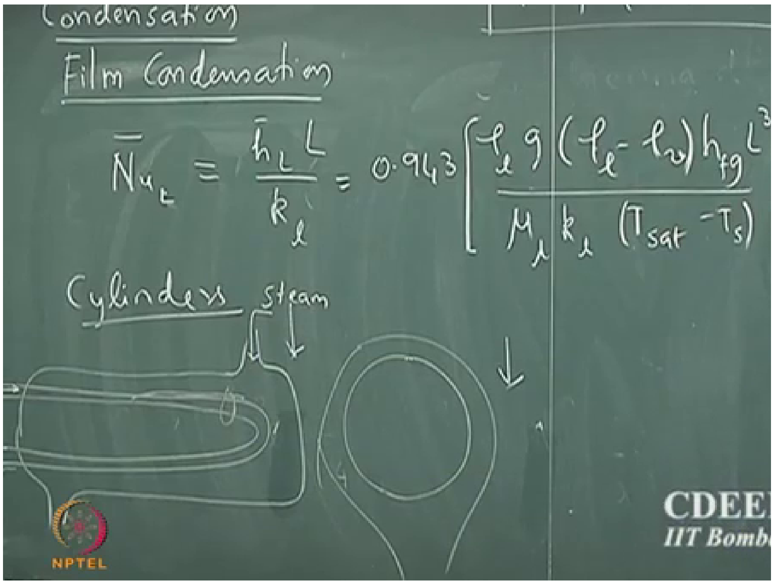


Based on the length of the plate the average Nusselt number which is divided by k liquid from that is given by 0.943 into rho l; g rho l minus rho v multiplied by into l cube divide by mu l, k l, T sat minus T s and the whole thing to the power of 1 by 2 ok; so that is what is the average Nusselt number ok. Now, we are done with the flat plate case; so, we can also look at the cylinders. I am not going go into the details of this cylinders other than it present what the expression for Nusselt number is. So, the cylinders is something that is also very very commonly encounted.

So, suppose I take a cylinder here ok; now I have a fluid vapor which is actually flowing pass this cylinder and I am going to have condensate which is going to form. So, let us flowing from top to bottom I am going to have a condensate and the condensate going to flow bottom side of the cylinder. So, very common application is if you look at a heat exchanger we see shell and tube heat exchanger, when we discuss heat exchanger problem.

So, in a shell and tube heat exchanger the way it look like is you have a shell and you have a tube which is going through it. So, this is just called as single pass we will worry about all that when we discuss heat exchanges. So, one of the common application is there is scheme which goes on the shell side ok.

So, you want to heat some fluid which is going on the tube side for example, there may be a reactor which is connected to the bottom uh exist of the tube side; you want to heat the fluid before it gets into the reactor. So, the fluid goes through the tube and you might have steam at the saturation temperature. So, what will you encounter is there will be condensate which will be formed along the curved surface of the tube.

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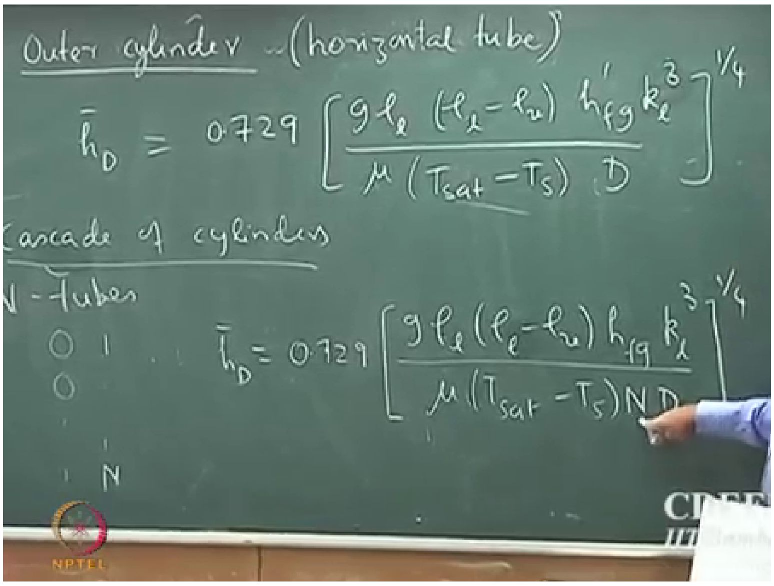


So, that is a place where the condensation crosses at the exterior of the cylinder or the curved surface of the cylinder plays and important role. So, these kind of correlation are actually very commonly used in the heat exchanges at the; so, the correlation. So, that is outer cylinder and it is a horizontal tube.

So, the heat transport average heat transport coefficient based on the diameter of the tube that is given by 0.729 multiplied by rho l, rho v; f g prime cube divided by (Refer Time: 13:30) that is the k liquid cube of that mu T sat minus T s into d to the power 1 by 4 ok. So, that is the average heat transport coefficient based on the diameter of the tube; an extension of that is suppose if I have N tube together.

Suppose I have cascade of this tube; so, remember that in the shell and tube heat exchanger, we saw that when steam comes through the shell side ok; you will have condensation on the first tube, you will also have condensation on the second tube. So, it is important to know what is the rate of condensation and the heat transport coefficient; you have many tube which are placed on certain line.

So, if I have N tube; so, we have tube placed one below the other 1 to N. So, if we have N tube like that; so, in that case heat transport coefficient can be extended to 0.729 multiplied by g times rho l, rho v; rho l minus rho v multiplied by latent heat k liquid divided by mu into T sat minus T s.

It is just multiplied by n turns out that is the appropriate heat transport average heat transport coefficient for (Refer Time: 15:22) feature actually N tube which is placed one below the other.

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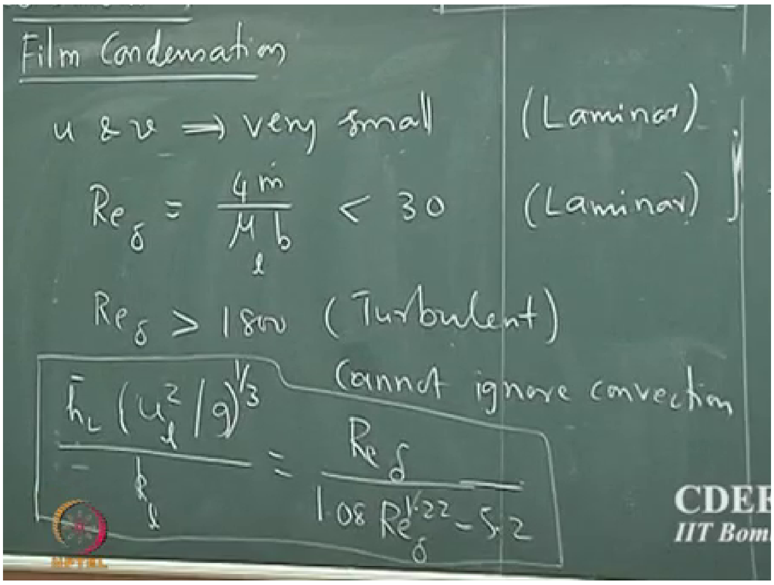


So, when we started this discussion we said that u and v are very small right. So, what will be the nature of the flow if u and v are very small? Small velocity? Come on velocity is small what is the nature of the flow? Is laminar right so what we looked at is laminar condition. So, one could also have turbulent condition for the same problem and so, the Reynolds number.

So, remember that the flow is only in the boundary layer. So, is the Reynolds number in the boundary layer is given by 4 m dot by mu l into b and so, if this is less than 30, then it is consider to be laminar; the flow is to be consider as laminar. And this is about greater than 1800 and considered to be a turbulent flow; considered to be a turbulent condition and; obviously, you cannot neglect cannot ignore convection effects cannot ignore convection and so, the heat transport coefficient for this k is given by this expression.

That is equal to divided by 1.08 minus 5.2; so, that is the correlation for heat transport coefficient under turbulent condition ok. Yeah v is the velocity of the liquid to be u f; the x component velocity. So, we will not go more into condensation; so, for the course purposes we will stop condensation at this point.

So, from the next lecture; we will start heat exchanges, we will look at what are the difference types of heat exchanges, we will look at how to characterize heat exchanges and what are design parameters and what is definition of shell tube heat exchanges?

All that you will see in the next.