Heat Transfer
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Lecture – 40
Boiling II

From the first stage.

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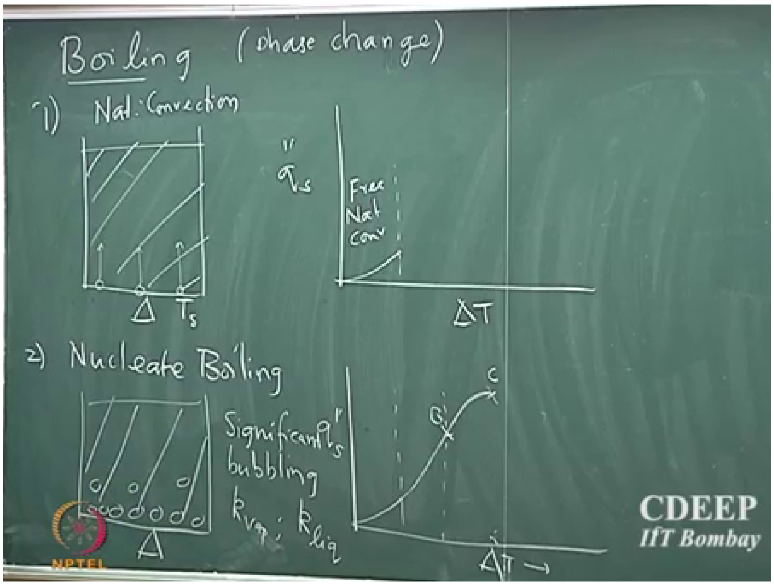

Suppose I take a beaker, which is filled with a fluid and. So, there will be a certain temperature range till that temperature, the process that occurs is only by the heat transpose only by natural convection and in fact, if I start to develop this boiling curve ok.

So, there is a certain region till which point the mode of primary mode of heat transport or dominant mode of the transport is the natural convection, and what happen is supposing I supply heat here and this is the temperature surface. So, what happens is there will be occasional bubbles which will be formed ok, sporadic bubbles will be form at the bottom surface, and because of the density difference they will start moving up and this will set up the recirculation motion in this container and so that passes the natural convection.

So, the primary I should say that dominant mode of heat transport here is (Refer Time: 01:43) by convection natural convection because of displacement of the fluid ok. Still the maximum contact of the surface of the fluid liquid takes, there will be sporadic bubbles which will be formed. So, the primary transport of heat is only between the solid surface and the liquid surface. I mean the liquid which is in contact to the surface ok.

So, this is what is called the natural convection mode of boiling, and then the second one is called the nucleate boiling nucleate boiling actually has two regions ok. So, the. So, the free convection is still this point. So, all the way up to the maximum if I called this as some maxima c ok, and this is again delta T verses the flux of heat that is supplied for boiling. So, what happens is. So, this is the fluid and I have heating system below. So, what happens is, till a certain point so there will be a inflection point of this curve ok

So, till the inflection point, you will see the there will be significant bubbling of vapors which will come here. So, the bottom surface will now have significant amount of bubbles and so, there will be significant bubbling. So, now, the heat transport is not just by the free convection, because there is good fraction of the bottom surface which is in contact with the vapor bubble. So, therefore, the heat transport is going to be both because of the sensible heat which is carried by the vapor, and the sensible heat which is carried by the liquid phase of same fluid.

So, now, the phase change has affected heat transport by both liquid and the vapor phases. Now what is the nature of the conductivity of vapor phase compared to liquid? It is always lower to the conductivity of a vapor phase is always lower than the conductivity of the liquid.

So, what happen is that till the inflection point, the still the majority of the energy is carried by the liquid phase and therefore, what you will observe is that the heat transport coefficient will continue to increase all the way up to the inflection point. Still the situation where the they have a switch in the amount extent of heat that is transported by the liquid or the vapor phase ok. So, that is the third stage, that is the third stage of boiling.

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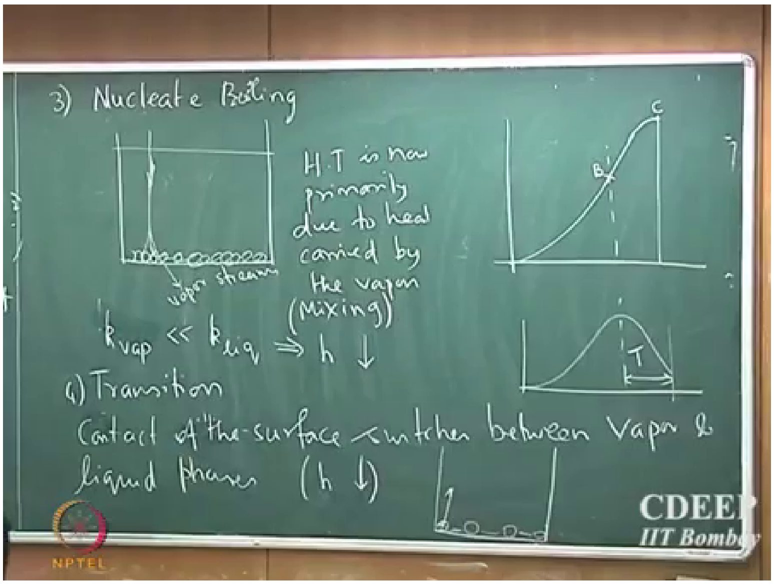

Where its still the nucleate boiling because it is still the mechanisms in nucleation nucleate boiling is that there will be significant vapor formation bubble formation of the bottom surface, and some of these bubbles because they are formed. So, close to each other they are going to (Refer Time: 05:30) each other and they well form what is called vapor stream. So these are the vapor streams. So, you well start seeing vapor stream which is going together. So, a channel of vapor is created, and so, the heat transport is now because of the heat that is carried by vapor phase. So, there will be a change in the dominant mode of heat transport.

So, the heat transport is now primarily due to heat carried by the vapor ok. So, the heat is primarily carried by vapor because the density of the vapor phases significantly smaller, and so the (Refer Time: 06:33) will occur very quickly and they also move very quickly. So, this is actually going to increases the recirculation in the in the fluid in this chamber and so, there will be vigorous mixing that will be introduced. So, the mixing is introduced in mixing is introduced in this particular stage. Now what happens is because the because the conductivity of the vapor is much smaller than the conductivity of the liquid ok.

So, the net amount of heat that is transported, remember the net amount of heat that is transported is going to reduce. So, therefore, we expected the heat transport coefficient it will start decreasing with the with the more vapor that is formed, and the reason behind is that the vapor which is formed is immediately transported out and so, they are not in complete contact with the bottom surface. So, the residence time for the vapor phase near the surface is very small and so, the contact time is small and all so, the conductivity is very small. So, therefore, the heat transport coefficient is start decreasing as soon as you reach the third stage and the boiling curve here is if I put so, that stage is all the way up to the maximum ok.

And what happen after that is for the transition stage where you cannot distinguish whether the bottom surface is now in contact only with the fluid or only with the vapor phase, it is going to be constant switch between the vapor and the liquid phase. So, therefore, the heat transport coefficient will continue to decrease because it is constantly switching and so, the residence time or the contact time between the fluid and the solid is going to be significantly smaller.

So, the transition stage of. So, the heat transport coefficient will continue to decrease. So, that is the transition stage is from the maxima to the minima. So, this is the transition stage and the last stage is the last stage called the film boiling.

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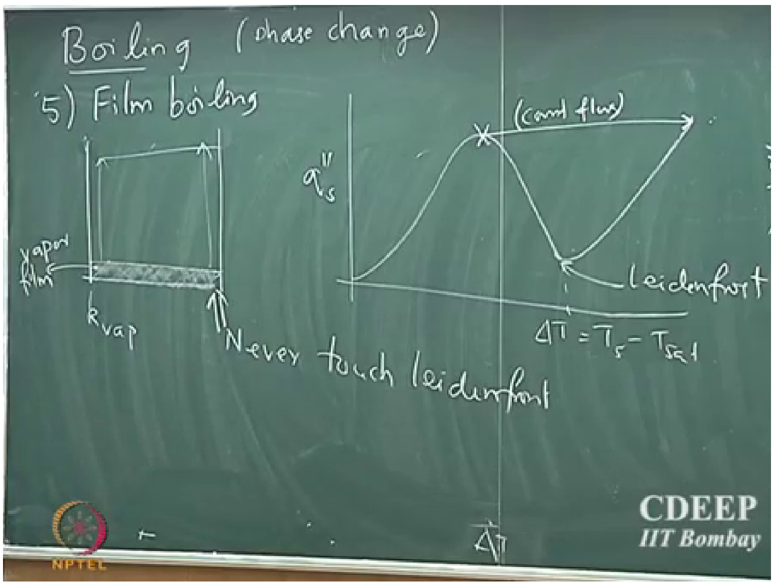

Now, at this stage the sufficient amount of heat that is been provided. So, the bottom of the container is now going to be filled with the a vapor filling. So, the temperature difference is significantly higher that any fluid which comes in contact with the bottom surface is going to be instantaneously converted into its vapor stage. So, the bottom surface will always be in contact with the vapor phase of the fluid. So, the primary heat transport is because of the conductivity of the vapor phase ok. So, the vapor will form and they will all escape out ok. So, that is the mechanisms and so, the boiling curve at that stage would be to they. So, now, as you further increase the heat that is provided. So, you increase the temperature difference this is T s minus T sat and therefore, the net amount the flux of heat.

That is carried is going to increase with increase in (Refer Time: 11:12) temperature difference. So, this bottom minima is called the is for historical purposes is called the Leidenfrost point ok. So, all though its seems so obvious for us when we see heating of water boiling of water that suddenly the vapor is form, it is not actually not that to be Lufia actually observed very closely, you will see these rigorous mixing you can see that and it is very easy to see this.

So, next time when you go your hostel and when there is water boiling and I do not know if your permitted kitchen and let us say if your permitted, you can actually see the boiling of water you will see that initially you will see the small bubbles which will come and slow they will come to the surface they will bust and they will go. And then after a while when you continue to supply heat further more you will see that there will be vigorous vapors which are formed and you will see these big bubbles which will come to the surface and start bursting.

So, the top surface will not the flat any more you will see the lot of vigorous vapors coming in and going out ok. So, that is actually they second stage oh third stage which is nucleate boiling where there is vigorous vapor which is formed and film boiling is the stage where you will see that most of fluid is already gone.

So, already being converted into vapor there is just well little fluid left and so, the bottom will now be filled with vapors, usually you never want to reach this stage. Mostly most of the time when you heat the water you never want to reach the stage of having filling of the bottom, because the filling temperature difference can be significantly higher it is not a most favorable condition never want to reach the stage.

You never touch the Leidenfrost point and so, what is typically is done is that once the fluid is reaches this maximum ok. So, the best way to boil a fluid is, you slowly go on reach the maxima on the boiling flow and then you maintain a constant flux condition maintain a constant flux and you reach here. So, this a constant flux. So, you provide constant flux of heat and then you go and reach the other end of this curve and that is how you ensure that most of the thinks is boiled. Never want to reach the Leidenfrost point because it is too much waste of energy oh ok. So, what happens is that in supposing I look at this is the beaker ok. Now what happens is here suppose let us say there is fluid which is present in this location and there is vapor bubble which is present here.

So, now, you can have a similar situation, we have vapor liquid vapor liquid. Now in transaction region the temperature difference between the surface and the saturation of the boiling point temperature is so, high, that whatever fluid that comes here is now going to be almost instantaneously converted into vapor phase ok. But it is still not significantly higher that at every location it will be converted into a vapor phase. So, therefore, as soon as the vapors are formed the vapors are now transported out from that location.

Therefore, what happens is that the contact time that this liquid or the vapor that has with surface is going to be significantly lower. So, therefore, the amount of heat that is transported in this regime is not going to be that significant, and that is why the heat transport coefficient actually goes down. Remember that heat transport coefficient only the a representative number it is a fictitious quantity is a representative number its tells you what is a extent of that is heat transported.

So, the extent of heat that is transported here is not significant because, there is constant exchange of fluid and vapor at the surface were the fluid is being heated, and that why the heat transport coefficient actually goes down significantly. I will I will draw in a minute how the heat transport coefficient profile will look like. So, the flux of heat transport ok. So, that should be heat transport coefficient multiplied by delta T fine.

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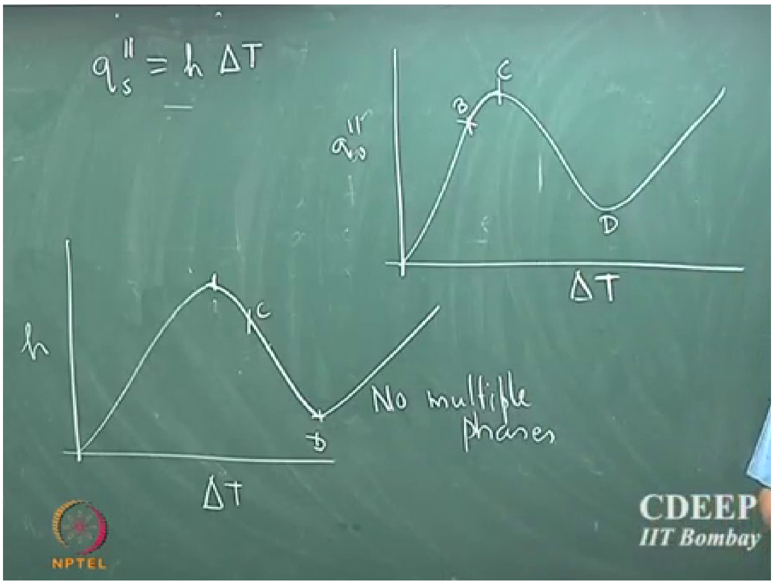

So, now, if I draw the to s versus delta T basically I have this behavior fine. So, now, what happens is that. So, h is actually can actually can be directly calculate from the boiling term.

So, if I plot the h versus delta T ok. So, what happens is that till the influxion point if I call this is b till the inflexion point the heat transport coefficient will continue to increase and the physical mechanism is done the liquid is still primarily liquid is in contact to the surface, which has a higher conductivity and therefore, it is enabling higher heat transport till that location.

Within moment it touches the influxion point, the offset in terms of the contact that you will have with the surface is significantly higher compared to the offset that you will get by the increasing the delta T. So, remember that u s is now function of both heat transport coefficient and the temperature difference. So, the; so, supposing if I want to I increase the flux here ok. Now increase in the flux here is because of the increase in the delta T and not because of the increase in the heat transport coefficient.

So, now, there this a competition between. So, if I now look at the flux now the increase in the flux is because of competition between increase in the temperature difference versus decrease in the heat transport coefficient, and the decreases the cause the contact is not completely fluid it is not completely vapor. So, there is going to be a mixture of both and so, the net effect is that the extent of heat transport is going to reduce.

And therefore, what you will see is that at the influction point you will the reach the location where there is a maximal heat transport coefficient, and the heat transport coefficient will start decreasing this location now c, I put c as the maxima point ok. So, it is not able to with stand the decrease in the heat transport coefficient. So, heat transport coefficient will now at this locate on c it decrease significantly lower and so, any increase in delta T is not going to increase in the to increase in the flux of heat transport ok.

Therefore, till the Leiden frost point where if I call this point D. So, till the Leidenfrost point were the bottom is now completely covered with the vapor film, the heat transport coefficient will continue to decrease and after that is single phases (Refer Time: 18:30) because the bottom whatever fluid that comes to the bottom is instantaneously converted to the vapor phase.

So, there will be a film of vapor which is always present on top of bottom surface. So, therefore, it now a single phase heat transport process. So, therefore, the heat transport is simply going to increase as you increase the temperature difference. There is no multiple phases here there is phase change, but no multiple phase that is in contact to the bottom surface of the container which is now heat in the fluid.

So, this is the kind of heat transport coefficient profile that you will get. See if you want to maintain bottom surface constant now you provide [vocalized noise] heat to the bottom surface, now you have to ensure that all the heat that is given to the bottom surface is now transported to the fluid. That does not happen because you have multiple phases here you cannot control that. You have multiple phases you have change in the phases now.

So, you cannot keep delta T constant any more. So, that is a problem. Until all the fluid now heated and converted into a vapor phase, the fluid will continue to be in at t sat temperature only the vapor temperature the local temperature will go about t sat, but they going to escape and go away. So, liquid is still continue to in t sat temperature the will continue to be at the boiling point, till all the liquid escaping into the vapor phase ok.

So, what we are going to do next 5 minutes so, is there is no way to get first of all there it not easy to guide the governing equations and therefore, there is no way to get analytical solution. So, there are some correlation which are available.

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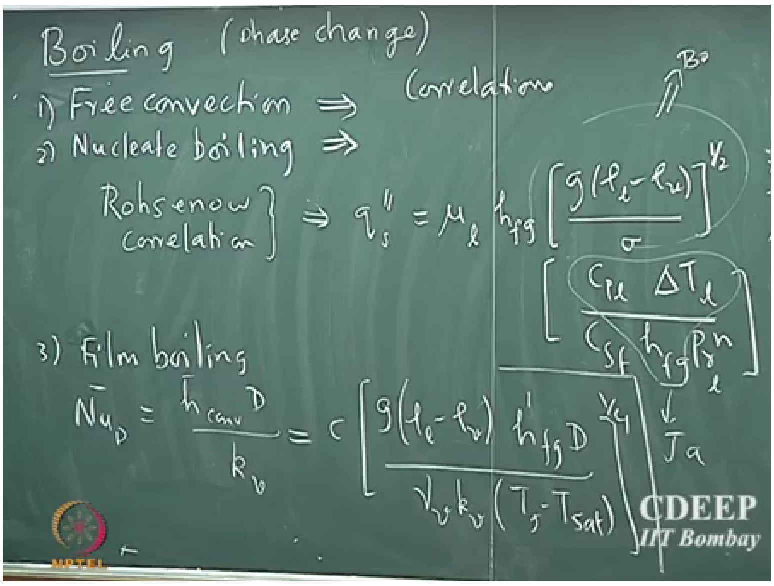

So, if you take free convection case, that is stage 1, we have already looked at some of these correlation. So, you have to use the correlation developed in we already know them. So, we already looked at natural convection problem. So, the second stage where you have nucleate boiling nucleate boiling. So, there is something called Rohsenow correlation.

Ok. So, now, this correlation essentially gives you what is the maximum flux, what is the maximum point, because that is what is a important for from operation point of you. Remember I do this (Refer Time: 21:17) where if you want to heat the fluid moment you touches the maxima you would like to maintain a flux condition. So, it is important to predict what is the maxima at which the boiling curve is going to reach. So, that is given by mu l multiplied by o v divided by sigma power of half multiplied by c.

So the C p delta T by h f what is that? Because it is dimensionaless quantity right that is the Jacob number. So, this is the Jacob number and what about bond number where is bond number? Expression it is here. So, some form is here you can reform it into bond number. So, (Refer Time: 22:34) a dimension (Refer Time: 22:35) actually present here. In fact, that is how the this equation is derived. So, in order to know what should be re functional form, you need to know what is dimensional (Refer Time: 22:47) are alright.

So, then uh. So, in the film boiling phase the Nusselt number, which is assuming that its aa cylindrical beaker that should be that is given by c into rho l rho v, c rho v, v T sat the power of 1 by 4. So, that is the correlation for Nusselt number at the film boiling phase. So, h f I have put up prime here, reason I have put a prime is depending upon the temperature difference. So, it could be either just the conduction mode of heat transport at the boundary or you could also have a radiation mode of heat transport ok.

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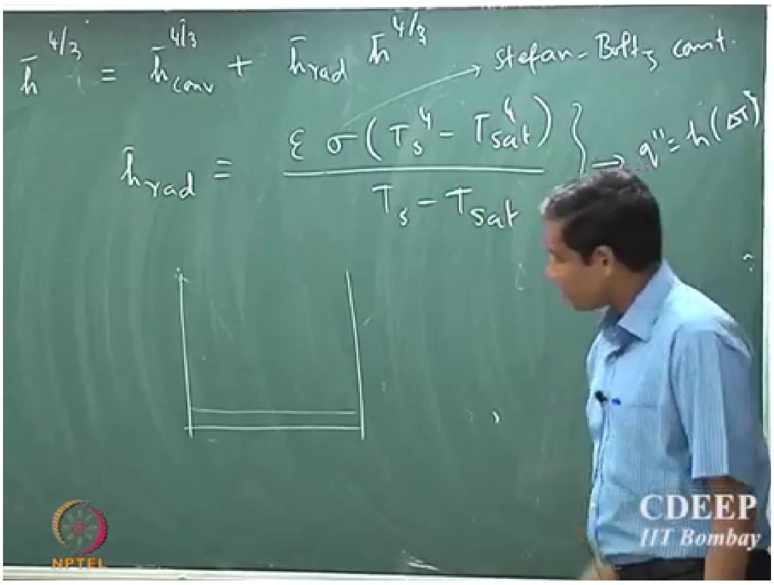

So, the. So, suppose if you have radiation mode of heat transport also, then the overall heat transport coefficient that you get which is h bar is related as h bar 4 by 3 convection plus h bar radiation into h bar to the power of 4 by 3 ok. So, note that is not linear. So, h bar radiation is defined as epsilon sigma T s to the power of 4 T sat to the power of 4 divided by T s minus T sat. So, it is very similar to the way we defined remember this comes from the flux equal to some h into delta T.

Use that definition to define heat transport coefficient because of radiation ok. So, epsilon sigma is Stefan-Bolts Constant surface tension Stefan bolts constant. So, this is the net radiation exchange between the bottom surface and the fluid which is actually present above the film. Remember that in the film boiling phase we will have a there is a film which is present and so, there could be radiation exchange between the bottom surface and the water which is present just above the vapor phase ok. So, that radiation exchange is given by epsilon is the emissivity multiplied by sigma into p s power 4 minus T sat to the power of 2. So, if you these quantity you should be able to calculate the heat transport coefficient.