Multiphase Flow
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Lecture No. # 36
Critical Heat Flux, Film Boiling

So, we were discussing critical heat flux, and today you will try to discuss are elaborate the hydrodynamic theory of critical heat flux. Now, critical heat flux will occur on any boiling surface, but to start with it is convenient to discuss critical heat flux over a flat surface. And again for the sake up convenience we will assume that the flux surface is of infinite expansion; that means, the surface is not bound by some walls show the (()) are not coming.

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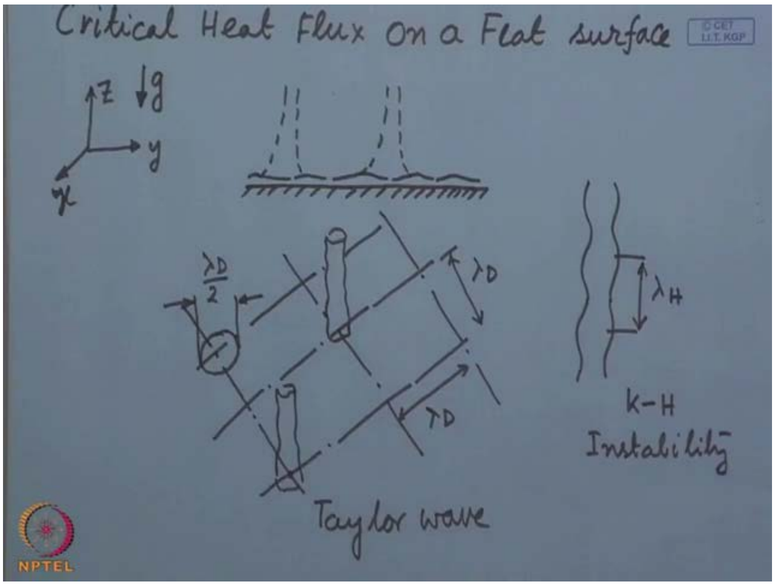

Now, critical heat flux on a flux surface we assume that if a contagion coordinate system x, y, z is present, where the ax[ix] gravitational if g that acts in the opposite direction of z. Then, the flat surface is extended up to infinity both in the x direction and in the y direction. A represented a representation of the flat surface could be like this flat surface is heated and on the flat surface over the flat surface there is cool of liquid. So, during film boiling we can assume that we can during critical heat flux we can consider that there is vapour formation. Now, this vapour formation is in an excess quantity.

So, that this vapour aims to form some sort of a film over the surface and this vapour film we have got the liquid. So, the vapour that has to escape and that will escape in a pattern. So, they will form a pattern of jets and then they will escape like this from the surface. Now, if you see if we consider the probe bue of the surface and the vapour release pattern. One will find that the vapour is leaving the surface in the form of jets from each node of this rectangular array which I have drawn; that means, at this node you will have same sort of a vapour jets or vapour column at this node you will have another vapour column similarly, at all the nodes you will have vapour columns.

So, this vapour columns are like this they are not straight they will have also undulations as has been shown in this diagram. So, you see they are a two in stabilities which are operational here first a low density fluid that is the vapour that is attach to the surface and above of it there is high density fluid that is the liquid. So, it gives rise some sort of is some sort of an instability which is known as Taylor instability on the other hand the vapour jets they are moving in the upward direction. So, they will have a relatively high velocity compare to the surrounding liquid. So, it will give rise to another kind of instability, which is known as Kelvin Helmholtz instability.

So, both this instabilities I have mentioned earlier. So, here we can get some sort of Taylor wave and in this case we can have some Kelvin Helmholtz instability. Now, see this Taylor wave will decide the distance between these columns and this distance is lambda D this distance is denoted by lambda d. So, any vapour column will be at a distance lambda D from it is never in column and then this is one wave length of the Kelvin Helmholtz instability. So, let us denote it by lambda h and also it has been seen that the jets diameter if this is the jets diameter this diameter is giving by lamda D by two. So, more or less this gives and idealistic view of the boiling phenomena, when it is at the critical heat flux.

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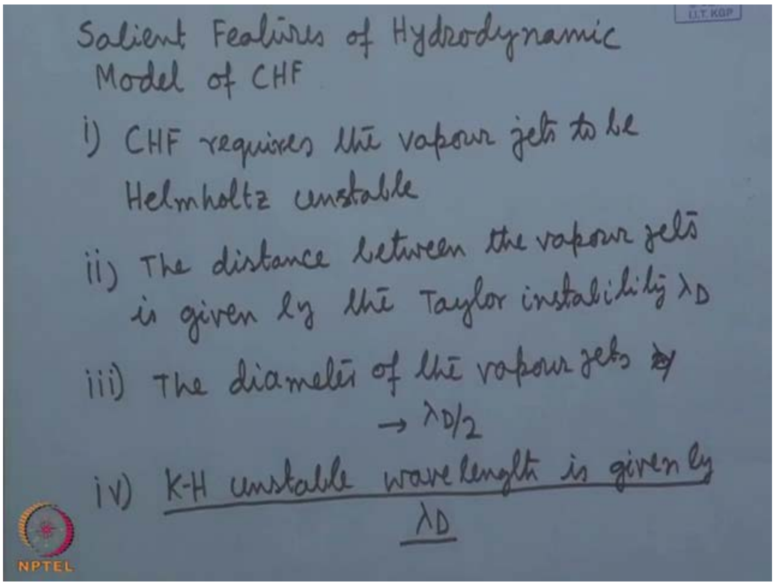

Salient Features of Hydrodynamic Model of CHF

i) CHF requires the vapour jets to be Helmholtz unstable

ii) The distance between the vapour jets is given by the Taylor instability λ_D

iii) The diameter of the vapour jets ~~by~~ $\rightarrow \lambda_D/2$

iv) K-H unstable wave length is given by λ_D

Now, you see there are some salient features of the hydrodynamic model; that means, certain assumptions have been made to develop this model. So, let us see what are this features? Salient features of hydrodynamic model of C H F first thing the critical heat flux obtained when the surface of the vapour jets becomes Helmholtz unstable. So, C H F needs or requires the vapour jets to be Helmholtz unstable. Second, the distance the distance between the vapour jets is given by the Taylor instability lambda D. Third, the diameter of the vapour jets that is lambda D by two.

So, these are very few, I mean very important assumptions that see each of requires. The vapour jets to be Helmholtz unstable when there is a growth of instability on the surface of the vapour jet; that means, they are will be growth of undulations and this undulations. When the wave length will be equal to the critical wave length of Kelvin Helmholtz instability we will have collapse of this pattern. And then we will have the critical heat flux and then how this vapour jets are form or at what pattern they are form they are at a distance of lambda D from the never in jet.

And each of the jet is having a diameter of lambda D by two. These assumptions have been made then another assumption this was made basically by lean hard and the here that Kelvin Helmholtz the unstable wave length k h unstable wave length is given by lambda D. So, this is another assumption this was not made originally by Juwar who propose this hydrodynamic model, but this was later proposed by lean hard and the here we will discuss regarding this after words.

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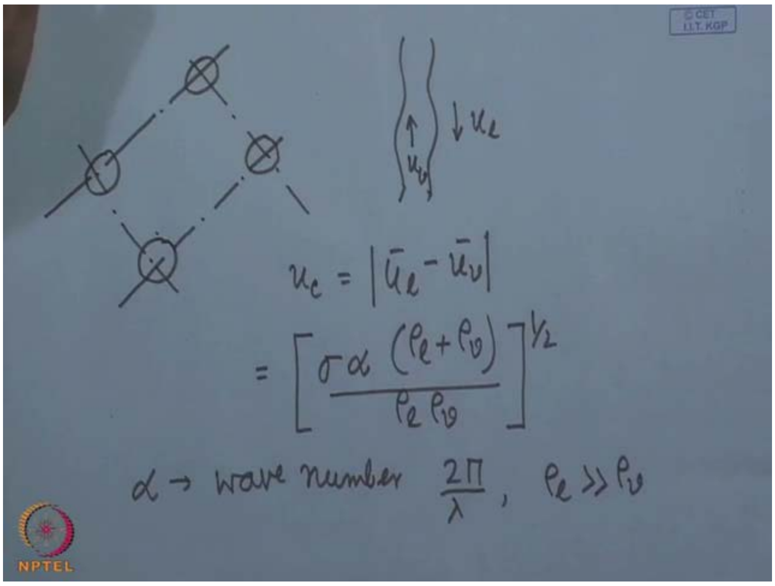

$$u_c = \left|\bar{u}_l - \bar{u}_v\right| = \left[\frac{\sigma \alpha \, (\rho_l + \rho_v)}{\rho_l \rho_v}\right]^{1/2}$$

$\alpha \rightarrow$ wave number $\frac{2\pi}{\lambda}$, $\rho_l \gg \rho_v$

Now, the then what we have got this kind of a figure we have got that if we see from the top the flat surface then number of jets are coming out this shows the base area of each of the jets and the jets are looking like this. Now, here the vapour is moving in the upward direction. So, we can call it u v vapour velocity u v as the vapour is moving in the upward direction. So, to replenish that the liquid has to come down in the downward direction we can call it u l and we know that Kelvin Helmholtz instability is dependent on the relative velocity between these two parallel strings.

So, u c that is given by u l bar u v bar; that means, we have to take care of the direction of this velocities also. And this has been proposed one relationship has been proposed for this relative velocity, which is given by sigma into alpha rho l plus rho v divided by rho l rho v whole to the power half. Here sigma is the surface tension of the liquid alpha is wave number, and it is given by two pie by lamda square. Lamda is the wave length and then rho l is the density of the liquid rho v is the density of the vapour further we can till that rho l is for greater than rho v.

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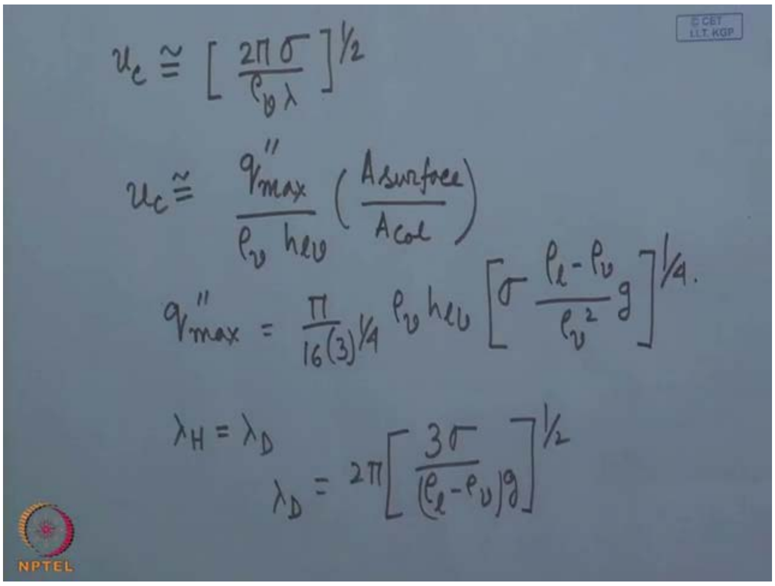

$$u_c \cong \left[\frac{2\pi\sigma}{\rho_v \lambda}\right]^{1/2}$$

$$u_c \cong \frac{q''_{max}}{\rho_v h_{lv}}\left(\frac{A_{surface}}{A_{col}}\right)$$

$$q''_{max} = \frac{\pi}{16(3)^{1/4}}\rho_v h_{lv}\left[\sigma\frac{\rho_l-\rho_v}{\rho_v^2}g\right]^{1/4}.$$

$$\lambda_H = \lambda_D$$

$$\lambda_D = 2\pi\left[\frac{3\sigma}{(\rho_l-\rho_v)g}\right]^{1/2}$$

So, compare to rho l rho v can be neglected in the rho l plus rho v term and if I do that then, one can get the relative velocity is approximately given by two pie sigma by rho v lambda to the power half. So, this is the relative velocity now, this relative velocity has been calculated from the Kelvin Helmholtz instability and from the wave theory. There is another way of calculating the relative velocity. What we can do? We can calculate the relative velocity by physically estimating the vapour velocity, which is in the upward direction and the liquid velocity, which is in the down ward direction. Again one can make an assumption that the vapour velocity is much higher compare to the liquid velocity. So, the u c u c can be from physical estimation u c can be approximated as q max double prime rho v h l v a surface by a column.

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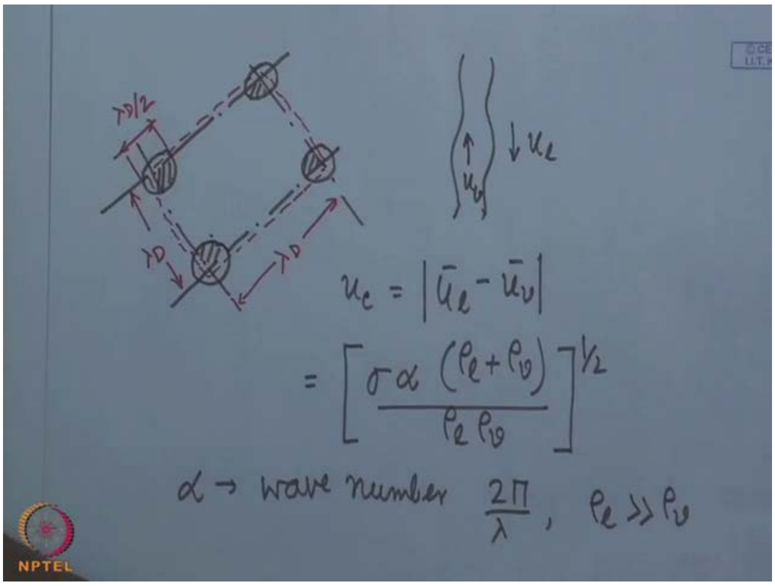

$$u_c = \left|\bar{u}_l - \bar{u}_v\right| = \left[\sigma\alpha\,\frac{(\rho_l+\rho_v)}{\rho_l\,\rho_v}\right]^{1/2}$$

$\alpha \rightarrow$ wave number $\frac{2\pi}{\lambda}$, $\rho_l \gg \rho_v$

So, we are assuming that critical heat flux is occurring q max or q max double prime that gives the critical heat flux rho v is the vapour velocity h l v is the latent heat of vapourization. Now, a surface and a column need some explanation. So, this diagram let us go back to this diagram let us take this area for our estimation of heat flux. Now, the heat, which is supplied to this particular area, is responsible for generating the vapour jet. So, how much vapour jet is generated? Here we can see one fourth vapour jet is generated here one fourth vapour jet and in the other two in each cases one fourth of vapour jet is generated.

So, if I take the distance is lambda D this distance is also lamda D and this distance is lambda D by two if diameter is lambda D by two. So, we can see that e may square area of lambda D square a vapour jet of lambda D by two diameter is generated. So, a surface or surface area denotes the area of this square whose side is given by lamda D. And the jet area is given by the circular area of the circle whose diameter is lambda D by two. So, basically with all sorts of simplification one can get q max double prime is equal to pie by sixteen three to the power one fourth rho v h l v sigma rho l minus rho v by rho v square into g whole to the power one fourth.

Here of course, one thing is important that we have to we have to assume that lambda h; that means, the wave length of Kelvin Helmholtz stability is equal to lamda D, that is the wave length of Taylor. And this lambda D is again given by two pie three sigma by rho l minus rho v into g whole to the power half. So, substituting all this thing the above equation for q max that has been optent. Now, the q max which has been optent here only one very drastic assumption has been made the drastic assumption is that the Kelvin Helmholtz instability the wave length which is the most dangerous wave length or critical wave length that is equal to the Taylor wave length of the Taylor wave.

Now, this assumption was made by lean hard and here of course, without much of a justification. But with this justification the result which one can get from the calculation of critical heat flux that gives much better prediction of the experimental data. So, many we search are they tent to adopt this justification and then whatever; value of critical heat flux we can get that is the accepted value of critical heat flux. Now, what you have done? So, far we have determined the critical heat flux for a flat surface.

And that to do we have done we have determine the critical heat flux for a flat surface oh, which is extended up to infinity both along the x direction and y direction. Now, in industry or in application we will have heaters of different geometry not that we will always deal with flat surface we can have critical heat flux over circular tube we can have critical heat flux over other geometry. So, how to how to determine or how to estimate the critical heat flux in those cases whatever, we have derived is it valid for all the other cases.

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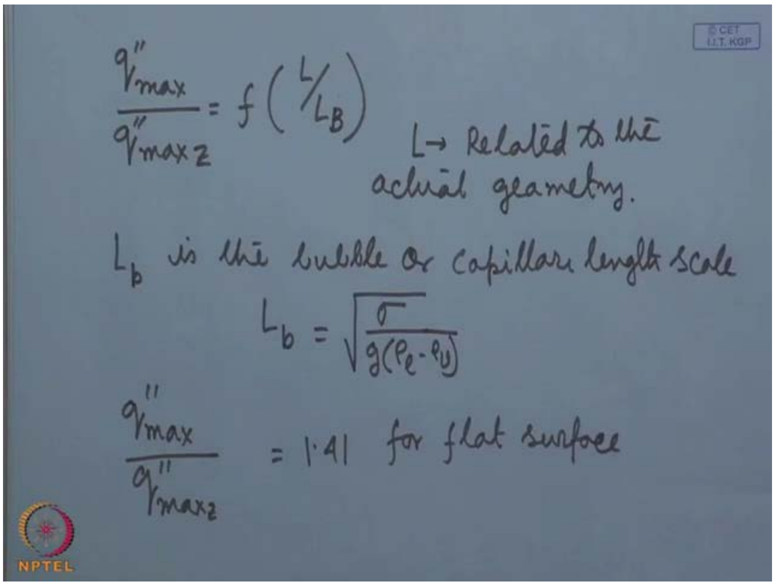

$$\frac{q''_{max}}{q''_{max\,z}} = f\left(\frac{L}{L_B}\right)$$

$L \rightarrow$ Related to the actual geometry.

L_b is the bubble or capillary length scale

$$L_b = \sqrt{\frac{\sigma}{g(\rho_l - \rho_v)}}$$

$$\frac{q''_{max}}{q''_{max\,z}} = 1{\cdot}41 \quad \text{for flat surface}$$

Now, in this direction some researcher, have some researches have to what and ultimately a relationship like this has been predicted or proposed. So, this relationship says that critical heat flux in other geometry that will be of that can be obtained from the critical heat flux, which juwar as predicted or juwars theory as predicted the critical heat flux. Just now, which we have derived and this is denoted by q max with subscript z this is given by a function of L by L v where l related to the actual geometry. L is a length scale which is related to the actual geometry L b is the bubble or capillary length. So, L b is given by if this expression we are familiar sigma divided by g multiplied by rho l minus rho v all within a square root.

So, this is the capillary length scale we are familiar with this using this lean hard and here they have found out that q max double prime divided by q max z double prime that is equal to one point four one for flat surface. Here I like to say that we theory which we have just now derived that was proposed by juwar, but that was marginally modified by lean hard and here. So, that why for flat surface what is propose by juwar and what is modified by lean hard and here there is a difference and this difference is given by this number 1.41.

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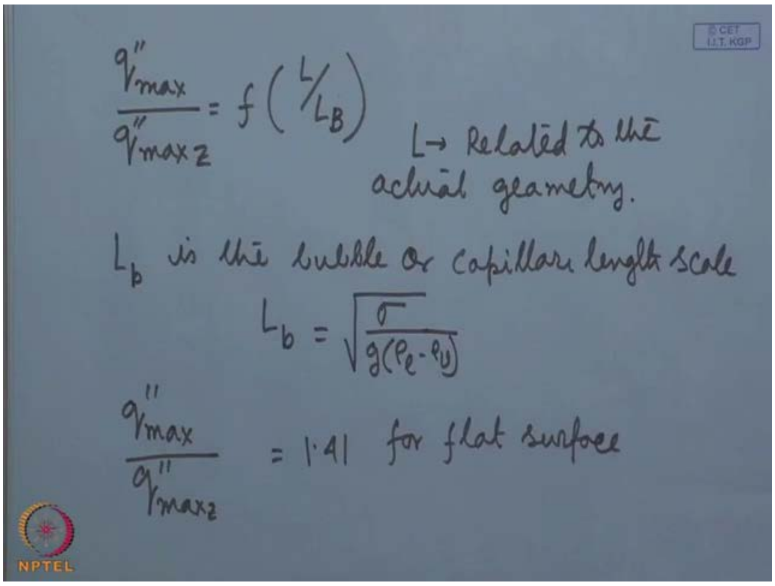

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$$\frac{q''_{max}}{q''_{max\,z}} = 1{\cdot}41$$ for flat surface

Another important case is that another important case is the critical heat flux over a circular cylinder for case circular cylinder. So, in that case again lean hard, and here have obtain this relationship this is equal to point one for large horizontal case cylinder. So, this is some sort of workable method for determining critical heat flux and in different books are hand books. One can get this q max double prime divided by q max jet double prime for different surfaces, which can be used as an when required for design or analysis purpose.

Now, the hydrodynamic model of critical heat flux it is not free from criticism or limitation if we list downs the criticisms then it is like this. Firstly, critical heat flux is a phenomenon which is covenanting from nuclear boiling, but what we are doing for predicting critical heat flux we are proposing all together a new phenomenology. The phenomenology which we had used for describing nuclear boiling that phenomenology is not being used here we are bringing some sort of new physics or new explanation. So, C H F theory not having relationship with those for nuclear boiling.

But it is one of the phenomena, when I mean it is a phenomenon related to the nuclear boiling or it is the terminal phenomena of the nuclear boiling. So, it should not be totally unrelated to nuclear body, but that what we have done in this particular case. We have proposed an entirely new physics for the explanation of critical heat flux. So, many people has got reservation for this. Secondly, the critical heat flux phenomena the wave. We have describe we have not taken care of it does not take care wettability of the surface, then it does not take care the surface roughness. These two parameters are of paramount interface a paramount importance in case of nuclear boiling.

But the critical heat flux theories do not include this one so; obviously, these are the weakness or limitation of the hydrodynamic theory of critical heat flux. There are other theories of critical heat flux already I have mentioned there is micro layer the during boiling there is a micro layer formation which I have explained earlier. So, from the micro layer point of view again one can have some explanation for critical heat flux. So, due to lake of time we are not going in to this, but basically from the force balance. And basically from the methodology, which juwar as mention there have been efforts to include the effects of wettability contact angle etcetera.

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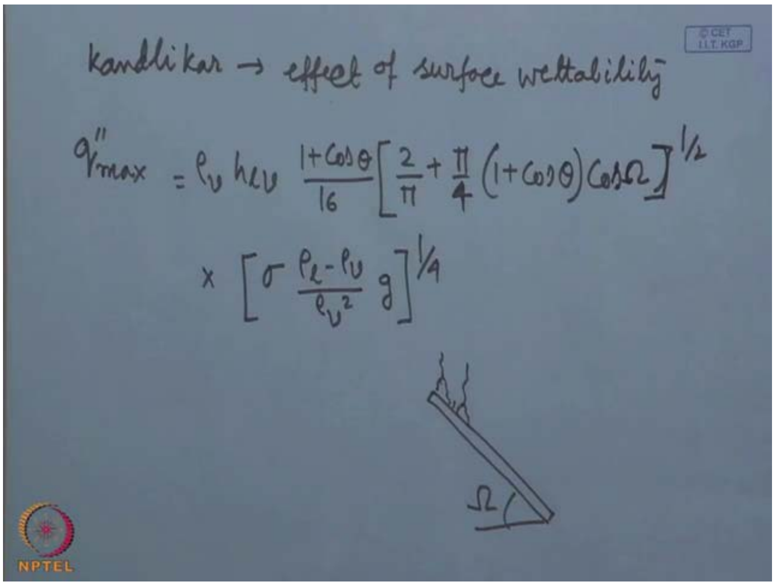

Kandlikar → effect of surface wettability

$$q''_{max} = \rho_v h_{lv} \frac{1+\cos\theta}{16}\left[\frac{2}{\pi}+\frac{\pi}{4}(1+\cos\theta)\cos\Omega\right]^{1/2} \times \left[\sigma \frac{\rho_l-\rho_v}{\rho_v^2} g\right]^{1/4}$$

One relationship provably can be told that is due to Kandli Kar. So, Kandli Kar he has taken care of the effect of surface wettability. So, in terms of contact angle the surface wettability he could take care of. So, he has proposed a relationship like this, q max is equal to rho v h l v plus pie by four one plus cos of theta cos of capital omega to the power half multiplied by sigma in to rho l minus rho v by rho v square in to g whole to power one fourth. So, this is a lengthy equal correlation or lengthy expression it is not a correlation it is a lengthy expression, but one can make it shorter if we take the ratio of q max double prime to q max jet double prime. Here theta is the contact angle and there is another parameter which has been which and which has been incorporated that is this capital omega.

So, capital omega takes care of the inclination of the surface for with the horizontal; that means, this particular expression is not only valid for horizontal surface it is also valid for critical heat flux from a surface which is inclined at an angle capital omega with the horizontal and let say this kind of vapour release pattern is clear. So, this relationship is really an extension of the earlier relationships of critical heat flux. Firstly, it takes care of the inclination of the surface on which boiling takes place and. Secondly, it takes care of the contact angle of the surface, which is very important in case of boiling.

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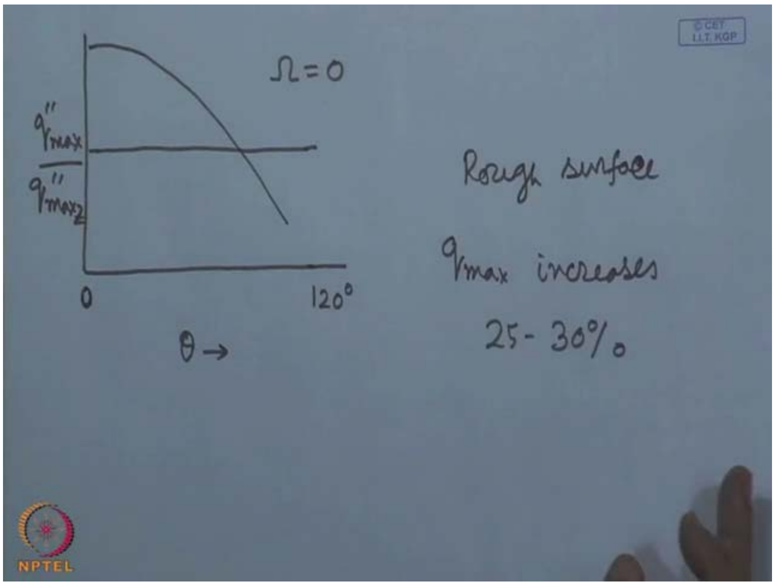

Now, if we make some sort of a comparison with the classical theory of critical heat flux. And the relationship which has been given by Kandli kar. So, this is q max jet the classical theory is independent of the contact angle which is theta let say we are thinking of a variation of contact angle from 0 to 120 degree; that means, highly waiting to highly non waiting type of contact angle. So, the classical theory will not predict any sort of variation of critical heat flux and if we now calculate critical heat flux from Kandli kar relationship. We will see that as the contact angle increases we will have a fall in the critical heat flux and then that fall could be quite large, when the surface is becoming non waiting. This particular graph is for a typical angle omega let say it is for omega is equal to zero.

So, you see that for critical heat flux we have got some hydrodynamic theory, which has got other limitations, but as the critical heat flux is quite a complex phenomenon. So, we this theory at least certain aspects of it we can explain and is as got reasonably good success in predicting the experimental data. But they are again some variations they are again some sort of discrepancy like it has been seen. It has been observed that, if we go for the theory which feeds while the boiling data from smooth surface, if we go for a rough surface then q max increases 25 to 30 percent. So, this is also observed. So, one have to care full while applying or adopting the result which has been given by the hydrodynamic theory.

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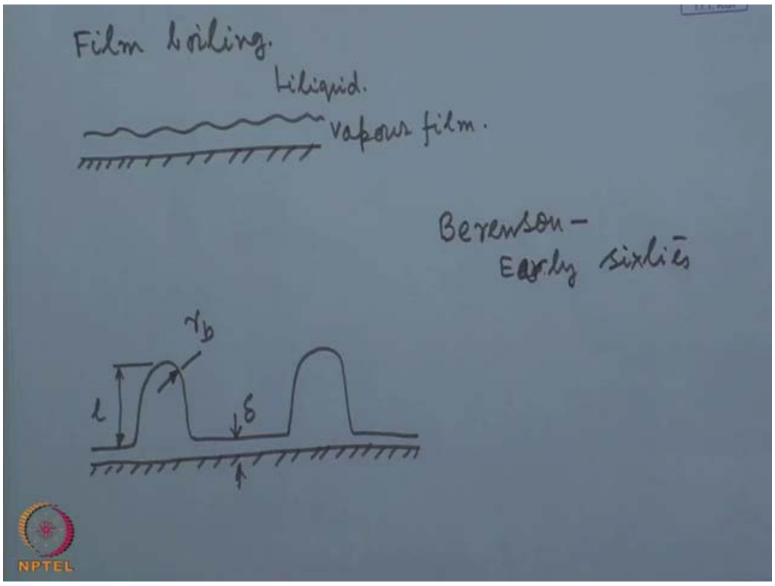

Now, let us go to another mode of boiling so we have discussed the nuclear boiling in detail. Then we have discussed critical heat flux in detail, which is very important from the safety point of view from industrial application point of view. Then we are coming to film boiling now, film boiling is not a very desirable mode of boiling heat transfer in most of the applications. So, people want to avoid film boiling in most of the application because it can it not only it gives a very low rate of heat transfer, but it can also lead to the failure of the heating surface. But the in then sometimes it is not awardable. So, one needs to know how to analyze film boiling. So, film boiling the heater surface is covered with a film of vapour.

So, this is your vapour film and at the top of it we have got the liquid and; obviously, the vapour film as it is having lower conductivity and it is some sort of a vapour. So, it will act as some sort of insulating layer and the rate of heat transfer will be much lower compare to the nuclear boiling. Now, what will be heat transfer coefficient that depends on many factors one of the factors that is the orientation of the surface let us very quickly see to two very common cases one is a horizontal surface and another is a particle surface. So, let us consider the film boiling over a horizontal surface if the surface is wide enough; that means, theoretically it is extended up to infinity both along the x and y direction.

So, one can expect to see this kind of a pattern there will be thin film of vapour over the surface and the film will be interpreted at regular interval by some dome like, structure to which vapour as to escape. So, the film thickness can be denoted by delta the nose radius of this dome that can be denoted by r b and the length this can be denoted by one with some simplifying assumption. And by the conservation equations like mass conservation momentum conservation one can determine all the geometrical parameters that is one r b and delta. In fact, long back Berenson. So, in the early sixties he has given a theory and from which one can calculate all this things.

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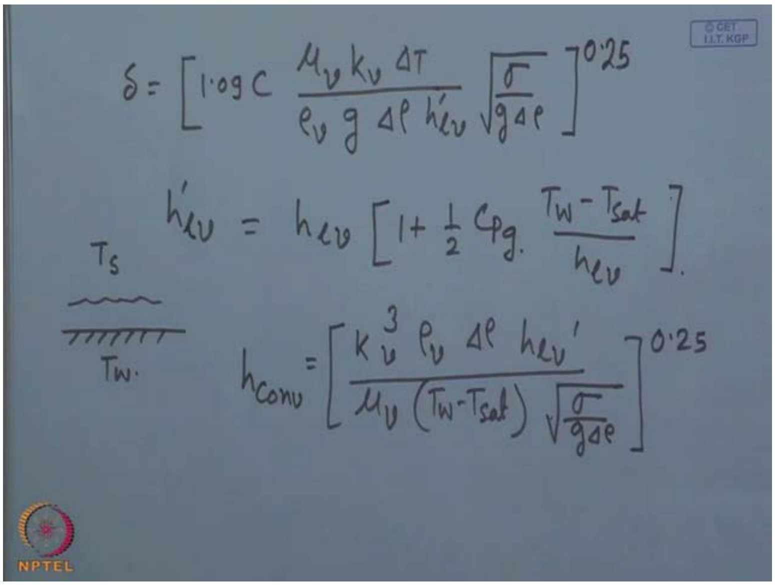

$$\delta = \left[1.09\, C \, \frac{\mu_v k_v \Delta T}{\rho_v g \Delta\rho h'_{lv}} \sqrt{\frac{\sigma}{g \Delta\rho}} \right]^{0.25}$$

$$h'_{lv} = h_{lv} \left[1 + \frac{1}{2} C_{pg} . \frac{T_W - T_{sat}}{h_{lv}} \right].$$

$$h_{conv} = \left[\frac{k_v^3 \rho_v \Delta\rho \, h_{lv}'}{\mu_v (T_W - T_{sat}) \sqrt{\frac{\sigma}{g\Delta\rho}}} \right]^{0.25}$$

Now, so what he has propose that it is a standing teller wipe and there is a laminar flow of vapour with this assumption one can calculate what is delta. So, delta that is the vapour film thickness that can be calculated as 0.09 C, which is a constant mu v that is the viscosity of the vapour K v is the conductivity of the vapour delta t is the temperature difference divided by rho v g delta rho the density difference between the liquid. And the vapour h l v h l v dash this is some sort of modified let in theta vapourization and then our known parameter sigma divided by g delta rho all within a bracket and to the power 0.25.

So, delta can be obtained by some sort of mass and momentum balance by this particular equation and c is same sort of numerical constant now h l v dash that is some sort of modified latent heat of vapourization because there is the wall is at a temperature T wall and liquid could be T saturated. So, there could be certain amount of degree of super heat for the vapour did not be at the circulation temperature. So, there is a way of calculating it. So, this will be h l v one plus half C p g this is the specific heat of the vapour T w minus t sat divided by h l v with this one can also calculate the conductive transform.

The conductive transfer that can be calculated as divided by mu v T w minus T saturated and sigma divided by g in to delta rho whole to the power 0.25. So, this gives approximately the conductive transfer during film boiling over horizontal surface. Now, this conductive transfer depends on a number of properties you can see number of sweet properties. And this property is mostly the property of the vapour and of course, some property of liquid is important the density of liquid is important. So, density of the liquid one can determined at the saturation temperature, but vapour you see at one end it is at saturation temperature at other end it is at the wall temperature which is quite high. So, the properties of the vapour should be calculated at some sort of average temperature.

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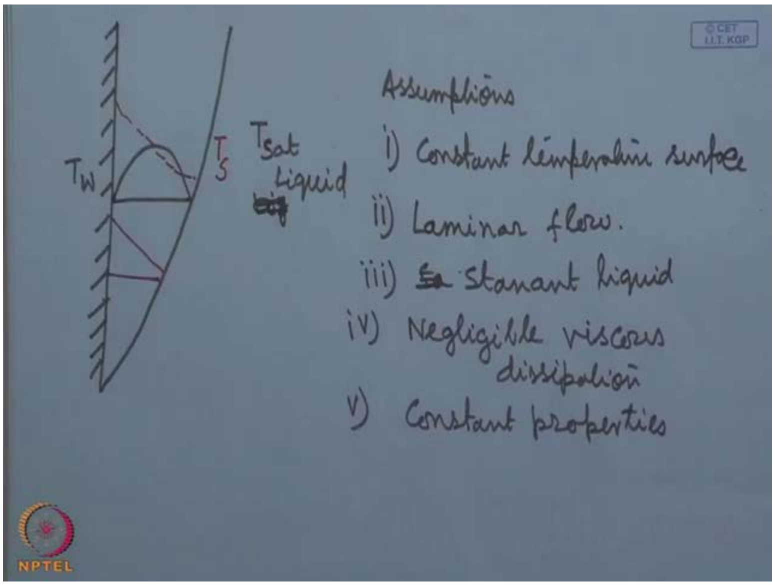

Assumptions

i) Constant temperature surface

ii) Laminar flow.

iii) ~~Sa~~ Stanant liquid

iv) Negligible viscous dissipation

v) Constant properties

So, this shows the case of film boiling over a horizontal surface most commonly we encounter film boiling over a biotical surface. And they are have been a different o a of estimating what is the heat transfer coefficient. So, this shows a biotical surface, which is at a constant temperature this biotical surface is a just two a liquid, which is at saturation temperature. This is liquid and as the as the wall temperature is quite high from the saturation temperature so film boiling is taking place. Now, the liquid could be moving with some velocity or liquid could be stationary if the liquid is stationary then one will have some sort of a velocity profile like this the velocity profile is such that the velocity is zero at the wall and the velocity is also zero at the interface.

One can also sketch the temperature profile temperature profile of course, as to reduce from the wall temperature T w to the saturated saturation temperature, which is T s. So, in general this is showing the nature of the temperature profile, but many cases one assumes some sort of a linear temperature profile the underline assumption is the vapour film is. So, thin that only conduction is effective in the vapour film convection is not taking place so we can do the analysis based on certain assumptions. So, assumptions if we note down one is constant temperature surface then laminar flow of vapour. Third stagnant liquid then, fourth negligible viscous dissipation then we can also assume constant properties. So, if we make all this assumptions and based on these assumptions we can write the momentum balance for the vapour page.

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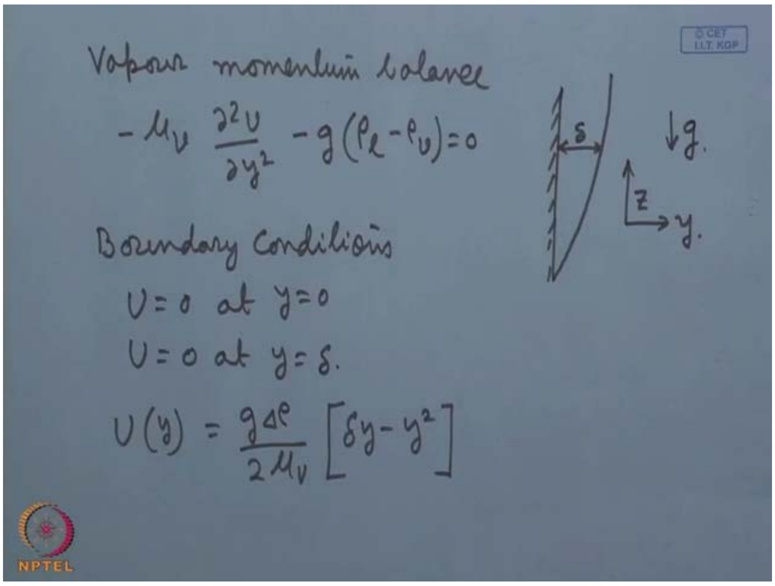

Vapour momentum balance

$$-\mu_v \frac{\partial^2 v}{\partial y^2} - g(\rho_l - \rho_v) = 0$$

Boundary Conditions

$v = 0$ at $y = 0$

$v = 0$ at $y = \delta$.

$$v(y) = \frac{g\Delta\rho}{2\mu_v}\left[\delta y - y^2\right]$$

So, if we write the momentum balance for the vapour page vapour momentum balance we will have mu v 2 v y 2 minus g rho l minus rho v is equal to zero. So, it will be convenient now if I show the coordinate basically we can take z in the upward direction and y in a direction normal to plate and this is the direction in which gravity works. So, with this we will get this momentum equation. So, the momentum equation can be solve with appropriate boundary condition. So, the thickness of the vapour film is delta and you can see delta is changing with the height that is z. So, if we if we have denoted the velocity as u. So, boundary conditions we can get u is equal to zero at y is equal to zero, u is equal to zero at y is equal to delta. So, these two are the boundary conditions for velocity. So, very easily one can find out u as a function of y that is a quadratic equation in y you will get for the velocity distribution along the direction of y.

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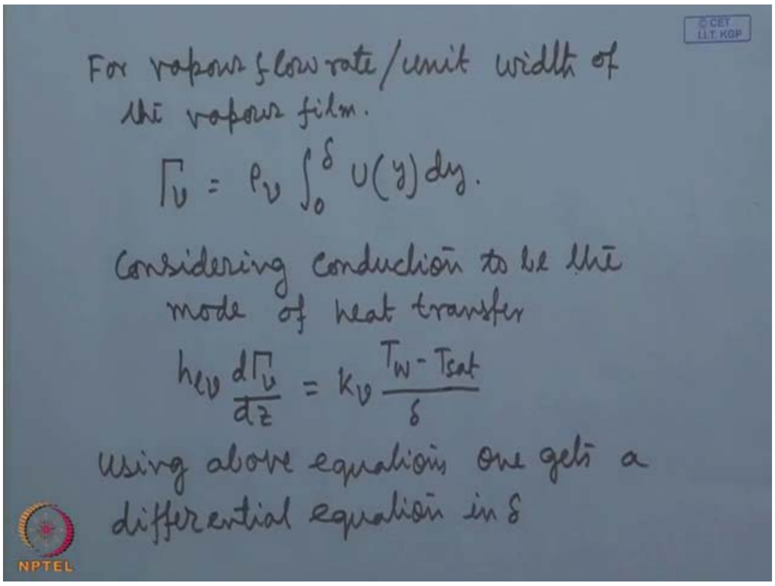

For vapour flow rate/unit width of the vapour film.

$$\Gamma_v = \rho_v \int_0^\delta u(y)\,dy.$$

Considering conduction to be the mode of heat transfer

$$h_{lv} \frac{d\Gamma_v}{dz} = k_v \frac{T_w - T_{sat}}{\delta}$$

Using above equations one gets a differential equation in δ

Then for vapour flow rate per unit width of the vapour film you will get tow v is equal to rho v. So, this will give you the vapour flow rate per unit width of the vapour film considering only conduction through the vapour film considering conduction to be the mode of heat transfer one can get h l v d tow l v d tow v d z is equal to k v T wall minus T saturated the delta.

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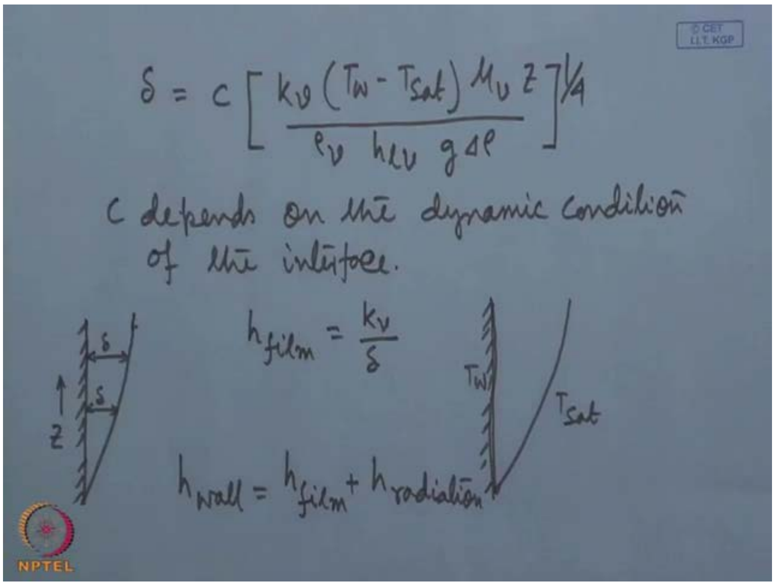

$$\delta = C\left[\frac{k_v (T_w - T_{sat})\mu_v z}{\rho_v h_{lv} g \Delta\rho}\right]^{1/4}$$

C depends on the dynamic condition of the interface.

$$h_{film} = \frac{k_v}{\delta}$$

$$h_{wall} = h_{film} + h_{radiation}$$

Now, in this equation and the equations which we have derived earlier using above equations one can get one gets a differential equation in delta. So, then delta can be solved and if we solve delta we get like this delta is equal to C. So, this is the equation we can get so, where C is a constant and c depends on the dynamic condition of the interface. So, you see delta then we are getting delta as a function of a z and other things of course, are the fluid properties. So, as we have already shown the schematic of film boiling over a particle surface. So, delta that is changing which z and that is so, what we have got from this relationship.

So, it is not a linear relationship it is a non linear relationship based on simplified assumptions once we have got delta we can get h film it transfer coefficient of the film boiling that is K v by delta. So, this is a very simple, but profound result and using some simplified assumption we have got the relationship for it transfer coefficient and based on this there are number of modifications done based on this one modification is that we can include conduction. The solution will be little bit difficult complex, but we can include conduction then another modification is that that we know that this is the saturation temperature and this is the wall temperature.

So, there could be some sort of super heating of the vapour and this super heat can be taken care of by modifying the by modifying the latent heat of vapourization this is another modification. But what is more important that the wall temperature is quite high and at that high wall temperature at that large wall temperature along with convection we have got also radiation. So, to make a proper estimate of heat transfer from the surface we should do h wall heat transfer coefficient should be h film plus h radiation again there is who is how one can do it.

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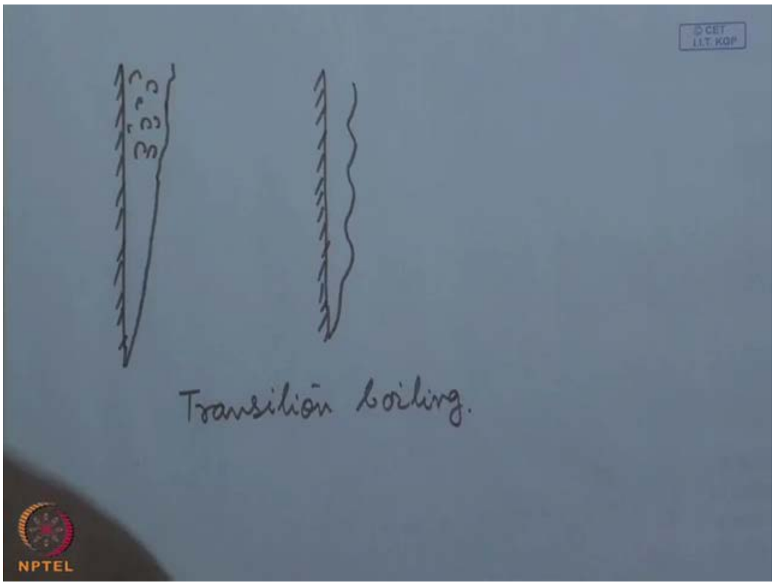

Lastly I want to say another thing that the analysis which I have done is having lot of limitation. We are assuming that the vapour film is laminar, but after certain distance the vapour film becomes turbulent. So, again for this portion then the turbulent analysis is important. Then in many cases one can see that the vapour film we have assumed this is a smooth interface, but it is not like this, as I have told there is Kelvin Helmholtz instability if there is relative motion between parallel layers of feeds.

So, due to that there will be undulations these undulations will up verse increase the heat transfer to some extent, but at the same time they make the analysis more complex. So, there are issues in film boiling which cannot be captured with the simply stick analysis which we have shown there are issues like other geometries other complex geometries there are issues like the effect of feed motion. So, this is just a beginning and the last thing, which I have now, which like to tell that in between nuclear boiling and film boiling there is another regime of boiling that is called transition boiling.

Now, our success rate for estimating transition boiling for relating transition boiling for explaining transition boiling is the minimum nuclide boiling we are partially successful film boiling. We are partially successful, but transition boiling really we are not that successful in predicting fortunately transition boiling does not occur over a long period of operation or over a long range of operation. That is why we did not bother about this transition boiling? So, much many cases what is done that we know the relationship for nuclide boiling we know the relationship of film boiling and transition boiling if you to think that it is a mixture of nuclide boiling and film boiling.

So, they can do some sort of weighted average of nuclide boiling and film boiling to predict the transaction boiling that is most of the cases predict that is what most of the cases is done, but obviously, we do not know much regarding the physics of the transition boiling. So, with this I like to conclude this series of lecture this as given you some back ground of phase change heat transfer. But our focus was mainly to boiling heat transfer and we have concentrated only on boiling heat transfer condensation. Heat transfer is completely different from boiling heat transfer and that could be covered in some other lecture series. Thank you.