Heat Transfer And Combustion in Multiphase Systems
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Lecture 38
Boiling-I

Okay. So, Welcome to this lecture! We started on boiling in the last lecture, if you recall that boiling and what is boiling and what is evaporation. So, we say boiling always involves the formation of bubbles. Now, there are two classes of boiling:

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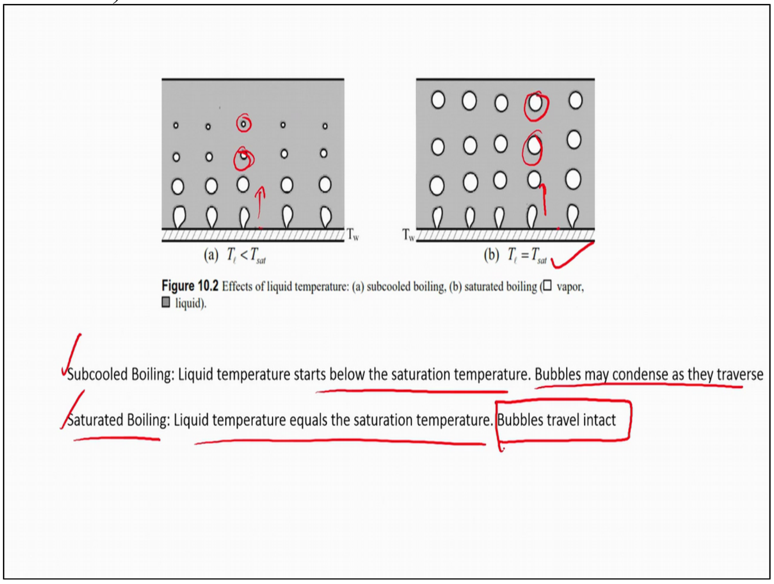

Figure 10.2 Effects of liquid temperature: (a) subcooled boiling, (b) saturated boiling (□ vapor, ■ liquid).

Subcooled Boiling: Liquid temperature starts below the saturation temperature. Bubbles may condense as they traverse

Saturated Boiling: Liquid temperature equals the saturation temperature. Bubbles travel intact

Basically one is, basically called sub cooled boiling, if you look at the text over here; one is called saturated boiling. Now, what is sub cooled boiling? Sub cooled boiling is that when the liquid temperature is starts below the saturation temperature. So, the bubbles actually detaches grows on the surface. It detaches, but, it then kind of become smaller and condenses as they traverse.

So, the liquid temperature is below the saturation temperature. So, essentially the bubble grows detaches become smaller due to condensation and then just goes off, right. When the liquid temperature is equal to the saturation temperature, right we get, what we call, Saturated boiling. In a saturated boiling, what happens is that the liquid temperature equals the saturation temperature.

So, the bubbles they grow, they detach and the traverse unharmed basically unaltered in size. So, the bubbles travel in an intact fashion, right. So, these are the basic two differences between sub cooled boiling and saturated boiling. So, these are the two major classes.

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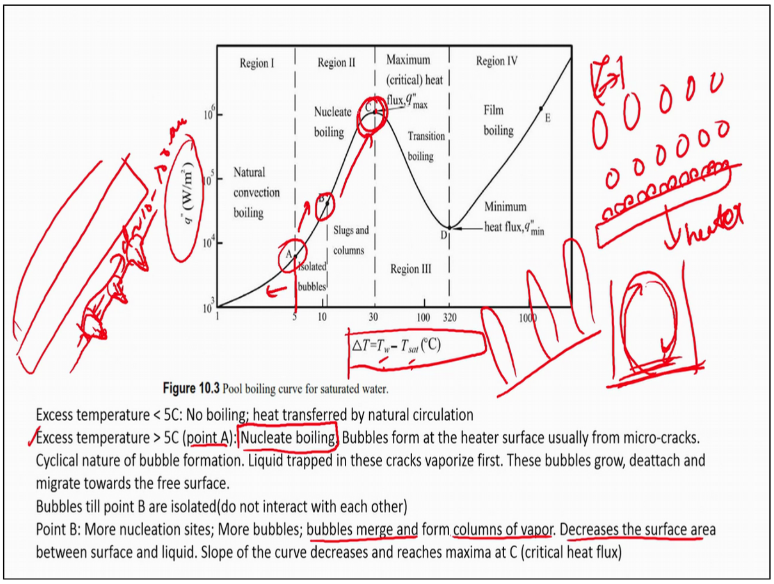

Figure 10.3 Pool boiling curve for saturated water.

Excess temperature < 5C: No boiling; heat transferred by natural circulation

Excess temperature > 5C (point A): Nucleate boiling. Bubbles form at the heater surface usually from micro-cracks. Cyclical nature of bubble formation. Liquid trapped in these cracks vaporize first. These bubbles grow, deattach and migrate towards the free surface.

Bubbles till point B are isolated(do not interact with each other)

Point B: More nucleation sites; More bubbles; bubbles merge and form columns of vapor. Decreases the surface area between surface and liquid. Slope of the curve decreases and reaches maxima at C (critical heat flux)

This is the most important curve that you will encounter in boiling, okay. So, boiling, this is basically the degree of superheat. Degree of superheat is nothing but the wall temperature away from the Saturation temperature, right okay. And this is the heat flux. So, what happens is that when the excess temperature that is the wall temperature minus the t superheated T saturation is less than 5 degrees Celsius that means less than this mark.

What you have is that, there is no boiling at all. The heat transfer is by natural circulation, right. So, it is like a basically a problem in which you have a heated surface underneath. So, there is a circulation current that is created, right because the layer of liquid near the surface gets heated. It loses its density; it climbs up, okay. And then, it comes down once again, gets cooler comes down.

So, you get set forward a basically a re-circulating stream, right. So, there is no boiling but the heat is transferred solely by natural circulation, right. If, on the other hand, the excess temperature is greater than five degree Celsius, if you look at this point, A now, what do you see? You see the first instance of bubble formation and this call is, this is called Nucleate boiling.

Nucleate means the bubbles actually nucleate from the surface. So, if you have a surface like this you will see that there are bubbles that will form on the surface like this, right. So, these bubbles form at a heater surface. So, this is basically your heater or the wall because you are hitting the wall, right. And the heater surface these bubbles usually form from the micro cracks on the heater surface.

So, if you look at this heater surface in a macroscopic view, it might look very smooth, right. If you take a basically a microscope and start to look inside, you will find that there will be these cracks of different kinds. And these cracks will have dimensions which will be like d will be of the order of it is a 10 micron 100 micron etcetera, right. So, these cracks basically serve as Nucleation point.

So, the bubble starts to grow from these cracks. This is because when you actually put a liquid over these, over this heater surface, the liquid cannot always penetrate through these cracks, right. So, some of their, as there is some entrapped vapour in this crack, right. So, that actually leads to this nucleation of bubbles. These bubbles grow detach and migrate towards the free surface, okay.

So, till this point B on this curve, okay and you can see there is a steady increase in the heat flux because more and more number of bubbles are forming, right. So, around B, when the degree of superheat is about 11-12 degrees, okay you will find that, till this point, the bubbles were mostly isolated. So, these bubbles were very separate from each other, right and we are moving up. They were very separate from each other, right.

So, they were not cross talking like we saw in the case of droplets that they were not cross talking. Here also, the bubbles actually do not cross talk with each other, okay. So, the bubbles till the point B are basically isolated. They do not interact with each other but beyond point B, okay, you get more and more nucleation of bubbles that starts to happen. So, these spaces start to become full of bubbles, okay.

These bubbles merge with each other and from columns of vapour, okay. So, you would not be able to see the single bubbles anymore. You will be able to see these slugs of vapours that are going up, okay. So, this decreases the heat flux from this point, from decreases the surface area so, the slope of the first starts to decrease. You reach a critical point C, okay where the slope reaches some kind of a maximum, okay.

So, C is called basically the Critical heat flux, okay. So, you start to form the slugs and columns. You get to the point C where the heat flux is kind of maximum, okay. But the slope of the curve starts to decrease at that particular point, okay.
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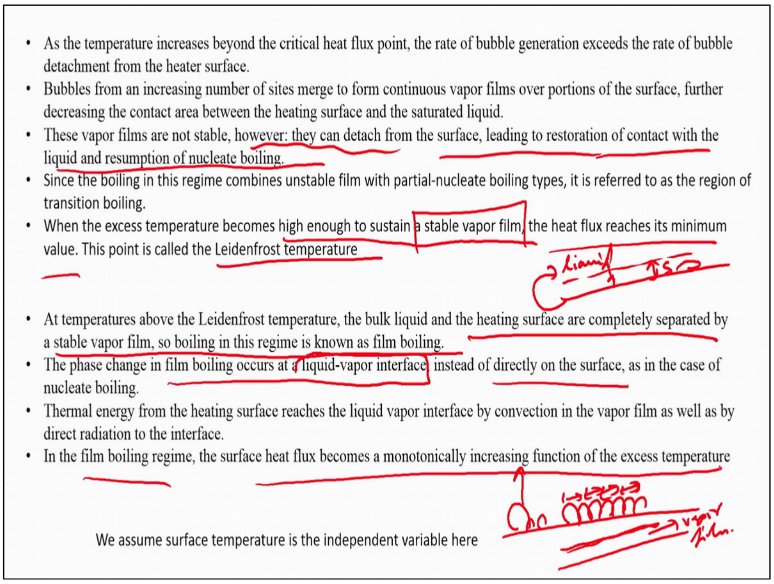

- As the temperature increases beyond the critical heat flux point, the rate of bubble generation exceeds the rate of bubble detachment from the heater surface.
- Bubbles from an increasing number of sites merge to form continuous vapor films over portions of the surface, further decreasing the contact area between the heating surface and the saturated liquid.
- These vapor films are not stable, however: they can detach from the surface, leading to restoration of contact with the liquid and resumption of nucleate boiling.
- Since the boiling in this regime combines unstable film with partial-nucleate boiling types, it is referred to as the region of transition boiling.
- When the excess temperature becomes high enough to sustain a stable vapor film, the heat flux reaches its minimum value. This point is called the Leidenfrost temperature
- At temperatures above the Leidenfrost temperature, the bulk liquid and the heating surface are completely separated by a stable vapor film, so boiling in this regime is known as film boiling.
- The phase change in film boiling occurs at a liquid-vapor interface instead of directly on the surface, as in the case of nucleate boiling.
- Thermal energy from the heating surface reaches the liquid vapor interface by convection in the vapor film as well as by direct radiation to the interface.
- In the film boiling regime, the surface heat flux becomes a monotonically increasing function of the excess temperature

We assume surface temperature is the independent variable here

So, as the temperature increases beyond the critical slugs, okay the rate of bubble generation exceeds the rate of bubble detachment from the surface, right. So, that means, if this is a surface, okay. Before these bubbles actually detach from the surface, more and more bubble starts to form, okay from the same place.

So, the generation rate exceeds the detachment rate, okay. So, the bubbles what it happens is that from multiple sides, even before they detach, they start to form they start to coalesce with each other, right. So, these bubbles start to cross talk with each other even before they are detaching, okay from the surface.

And what they do is that the form of film, this is like a vapour film. So, okay, over portions of the surface, right so, this decreases. What this does is that it is like a vapour cushion that you have formed, right. So, there is no direct contact, now, between the liquid and the heated surface, right.

So, there is no direct contact as a result of that the contact area, basically reduces, okay. And so, naturally, what tends to happen is that now, the heat has to be transferred through this vapour layer. So, the heat from the surface goes to this vapour, from the vapor it goes to the liquid, okay. And this vapour films, however, are not stable.

They can detach from the surface and lead to restoration of the liquid and the resumption of nuclear boiling. So what happens is that this vapour films can actually get detached from the surface also, okay. And fresh liquid can come and wet the surface, okay. So, you get a re-initiation of this nucleate boiling, okay.

So, because it involves this kind of an unstable film and partial nucleate boiling type, this is basically called the Transition boiling in this particular case, right. So, in this is called trans, beyond the critical heat flux from C to D. If you look at it, this is basically called the Transition boiling.

Transition boiling involves what? The bubbles from the nucleation sites basically cross talked with each other because there is a lot of bubble generation that happens because the degree of superheat is really high. It is of the order of 30 to 320, you can see from that graph, right. It is from 30 to 320. So, it is really what happens is that, this bubble starts to cross talk with each other. They merge they form of a vapour film.

Now, this film may not be stable all the time, right. So, sometimes this film gets detached. Fresh liquid comes and wakes the surface and you get nucleate boiling. Sometimes, this film actually acts as a cushion, okay preventing the liquid from coming in contact with the surface, okay.

So, that actually leads to ah, what we call a decrease in the corresponding heat flux values because of the formation of this vapour film, right okay. Now, when the excess temperature becomes high enough to sustain a stable a person before unstable, right the heat flux reaches its minimum. This point is called a Leiden frost temperature. This point is basically called the Leiden frost temperature, okay.

For the vapour film, what happens is that it was unstable at one point of time, it becomes really stable. That means the vapours film is stable it does not get detached from the surface. So, that corresponds to the minimum heat flux limit and the temperature and that particular point is basically called the Leiden frost temperature.

At temperatures above the Leiden frost temperature, if you go above the Leiden frost temperature, the bulk liquid and heating surface becomes completely separated by a vapour film. So, this is called basically film boiling. The phase change in film boiling occurs across the liquid vapour interface instead of directly on the surface.

So, there is a liquid and a vapour that is how the heat is transferred. So, if this is the surface, there is a vapour film of Delta that sits over it. And then you have the liquid. So, it is not the heat directly transferred from there to here. It passes through this vapour layer, okay. So, it is basically a liquid vapour interface across which the heat is transferred, okay.

So, the thermal energy from the heating surface reaches the liquid vapour interface by convection in the vapour film. So, within the vapour film, there is convection and that is how you actually get to the interface. It can also happen by direct radiation. Now, in the film boiling regime, the heat flux becomes monotonically increasing function of the excess temperature.

So, in this regime, the heat flux goes up like that, okay. So, the heat first goes to the vapour film. The vapour film actually gets heated. It transfers the heat to the liquid either through interfacial processes or through radiation, right. So, that is how the film is actually done and this is called regime IV which is called the film boiling.

At the end of this regime IV, you can have the catastrophic limit also, right because you can see that degree of superheat is very, very high, right because the degree of superheat is very high material of the heating surface, naturally melt, okay. So, you have a catastrophic situation. In many of the cases this boiling is done by putting in a wire, a heated wire within the liquid, okay.

So, this wire actually acts as the heated surface and you get all the events like nucleation so, what happens is that this we are actually melts. So, it just detaches, okay. So, you just have the end of the whole process. So, material integrity is one of the key factors, okay when you look at that kind of a regime, okay.

So, here, of course, we assume that the surface temperature is the independent variable and heat flux is the dependent variable in most of the cases which other way around, right. D control the heat flux and the surface temperature adjusts accordingly, okay? So these are the four regimes. Let us just revisit once.

Initially you have no boiling, then, you start having isolated bubbles, then you actually start to having slugs and columns that goes up here, the heat flux becomes maximum, then you have something called a transition case, in which, there is a vapour film that actually forms over the surface.

But that vapour film is unstable, so it is on and off kind of the vapour film. So, you get to a situation when you actually have a stable vapour film that is called the Leiden Frost limit. And then, you slowly have this increase in the, in the in the heat flux because you go to the film boiling regime where there is a vapour basically that guards the fluid, the liquid from the heated surface.

So, the heat is transferred not from the surface directly to the liquid, it is actually transferred to the vapour film and the vapours will through convection and radiation, basically transfer the heat across the liquid vapour interface to the liquid. So, that is what happens in this particular case, okay. So, these points should be this is the critical heat flux. This is the little frost point and there can be the catastrophic limit at the end of the journey, okay.

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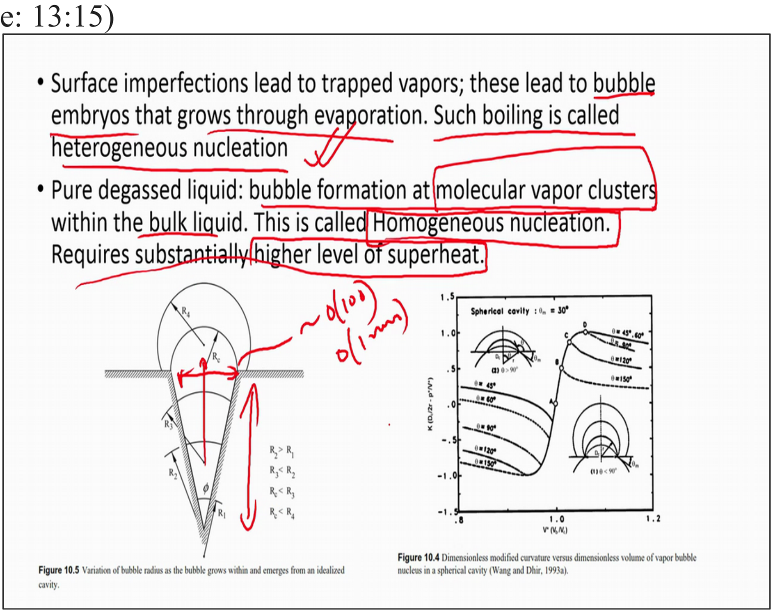

- Surface imperfections lead to trapped vapors; these lead to bubble embryos that grows through evaporation. Such boiling is called heterogeneous nucleation
- Pure degassed liquid: bubble formation at molecular vapor clusters within the bulk liquid. This is called Homogeneous nucleation. Requires substantially higher level of superheat.

Figure 10.5 Variation of bubble radius as the bubble grows within and emerges from an idealized cavity.

Figure 10.4 Dimensionless modified curvature versus dimensionless volume of vapor bubble nucleus in a spherical cavity (Wang and Dhir, 1993a).

So, now, there are different other cases of boiling also, okay that we will see over here. That there are two different classes of boiling, apart from the point that we mentioned already like: There can be boiling due to surface imperfections which we already said, okay. That is the surface has got this micro-cavities like this, this is zoomed in view of a cavity and this length scale can be of the order of microns, hundreds of microns.

It can be of the order of one millimeter also depends on what surface you are dealing with. This leads to what we call bubble embryos that grows through evaporation, okay. So, it leads to an inception of a bubble that is like an embryo, right. And this bubble slowly grows like the entire growth process has been shown in this particular diagram. Such boiling is called what we call Heterogeneous nucleation. It requires the surface.

Now, the last lecture, if you recall that we saw that the droplets actually undergo this kind of diffusional entrapment induced boiling. That is called Homogeneous nucleation. In Homogeneous nucleation what happens is that say you are dealing with a pure degassed liquid, okay. Now, bubble formation in those cases happens at the molecular vapour clusters, okay within the bulk liquid. This is called Homogeneous nucleation.

That means there is no surface involved. But, this requires a substantially higher level of superheat which we already said over here, that the degree of superheat can be almost as high as a critical temperature, right. So, that degree of superheat is very important, in those cases. In the case of heterogeneous nucleation, however, when you have particles, where we you have some media on which these bubbles can actually grow, right.

So, that is called heterogeneous nucleation. And the degree of super heat requirement is very low as you saw in the boiling curve, right. Beyond 5 degree Celsius, you start to have bubbles, right. But you cannot have the same thing when you actually have your degassed liquid because in those cases you can only have homogeneous nucleation, right.

That happens on the molecular vapour clusters and that requires a substantially higher level of superheat, okay. So, what we learnt is that these are the sub-cooled boiling. There is a difference between boiling and evaporation, sub-cool boiling, saturated boiling. Then the boiling curve which is the most important thing that you would get.

And this is a very typical boiling curve. This is done for water saturated water. It can be done for others; other types of things also. And we learnt the different stages of that boiling. And now, we know that there is something called heterogeneous nucleation and there is something called homogeneous nucleation of the boiling, right, okay.

And so, what we are going to do, right now is that we are going to study that what will be the, what will be, how we can analyze this kind of problem okay, in a little bit more details, right okay. So, let us go and do that.

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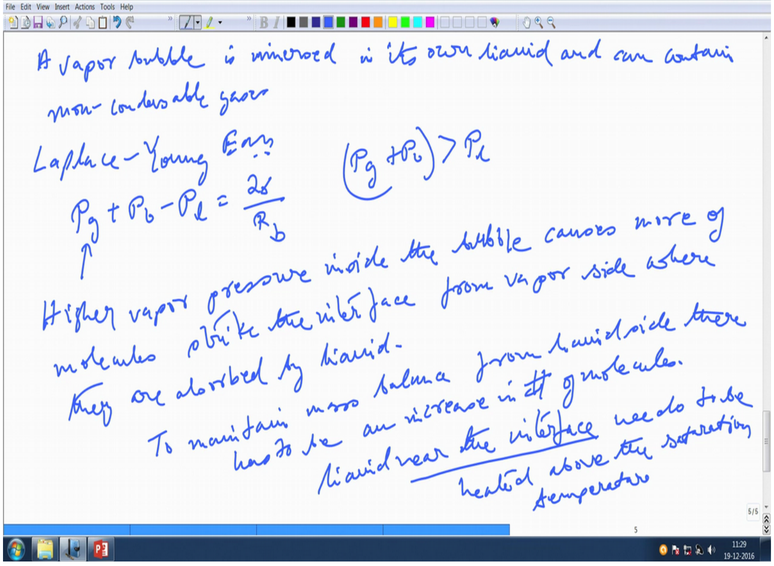

A vapor bubble is immersed in its own liquid and can contain non-condensable gases

Laplace-Young Eqn:

$$P_g + P_b - P_l = \frac{2\sigma}{R_b}$$

$$(P_g + P_b) > P_l$$

Higher vapor pressure inside the bubble causes more of molecules strike the interface from vapor side where they are absorbed by liquid.

To maintain mass balance from liquid side there has to be an increase in # of molecules.

liquid near the interface needs to be heated above the saturation temperature

We start with the problem in which our vapour bubbles. And this would be not very difficult a vapour bubble, okay is immersed, okay, in its own liquid, okay in its own liquid, okay and can contain non-condensable gases. Yes, if you look at, for example this, the problem is somewhat like that this particular figure, okay.

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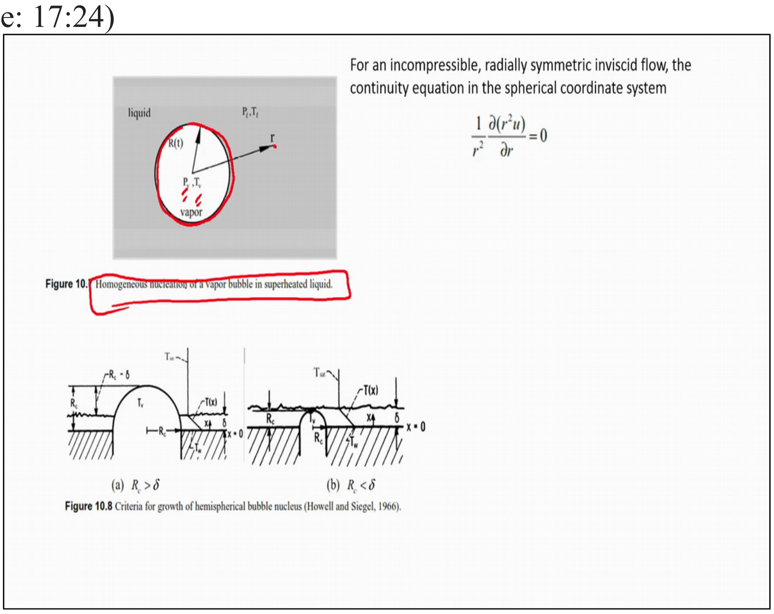

For an incompressible, radially symmetric inviscid flow, the continuity equation in the spherical coordinate system

$$\frac{1}{r^2}\frac{\partial(r^2u)}{\partial r}=0$$

Figure 10. Homogeneous nucleation of a vapor bubble in superheated liquid.

(a) $R_c > \delta$ (b) $R_c < \delta$

Figure 10.8 Criteria for growth of hemispherical bubble nucleus (Howell and Siegel, 1966).

Let me just pull it up. So, this is basically our vapour bubble. This is immersed in its own liquid, okay the pressure, the pressure and temperature inside the bubble. This is r the radius of the bubble; this is r at any other location outside the bubble in the liquid. So, this vapour bubble is growing. This is a homogeneous nucleation of the vapour bubble in a superheated liquid. So, that is a problem statement right, okay.

So, that is the problem statement that we are dealing with. It is a homogeneous nucleation of a vapour bubble in a superheated liquid. That is what we are going to study in this particular problem, okay. And then, we are going to see that how other types of bubbles actually grow. So now, you understand, so we are going to study this.

So, we write the Laplace Young Equation, Equation and this can contain condensable gases. So, that is why you have retained this term Pg over there, right. So, it can have non-condensable gases, as we can easily see that Pg + Pv is greater than P l, right. So, this essentially implies one and only one thing that the higher vapour pressure inside the bubble, causes more number of molecules strike the interface from vapour side okay.

Where they are absorbed by the liquid okay, now, to maintain a mass balance, to maintain mass balance, right the mass has to be maintained in equilibrium, maintained mass balance, okay. There must be a corresponding increase in the number of molecules emitted through the interface from the liquid side, okay.

From liquid side, there has to be has to be an increase in number of molecules, right okay. So, this leads to one thing. This leads that the liquid near the interface needs to be super heated above the saturation temperature, okay. So, the liquid near the interface, remember, near the interface, mark the words, near the interface needs to be to be heated, okay above the saturation temperature, got it. It needs to be heated above the saturation temperature, okay.

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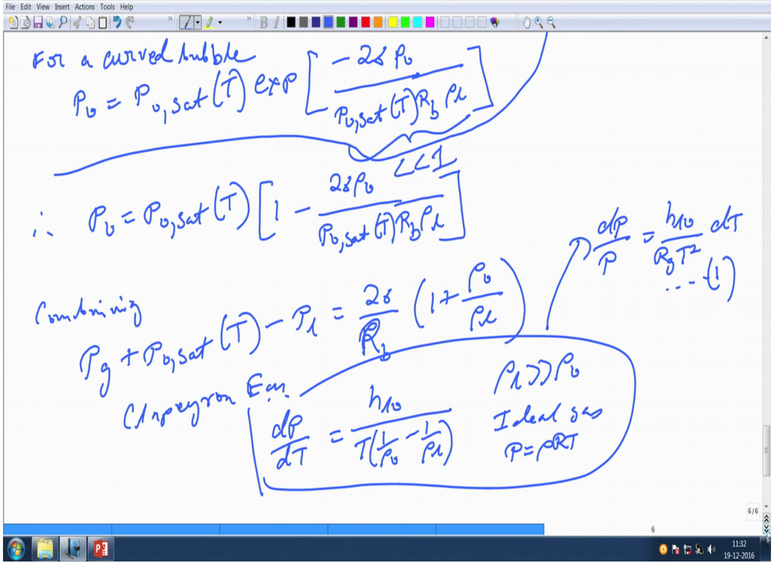

For a curved bubble

$$P_v = P_{v,sat}(T)\exp\left[\frac{-2\sigma\rho_v}{\underbrace{P_{v,sat}(T)R_b\rho_l}_{\ll 1}}\right]$$

$$\therefore \quad P_v = P_{v,sat}(T)\left[1 - \frac{2\sigma\rho_v}{P_{v,sat}(T)R_b\rho_l}\right]$$

Combining

$$P_g + P_{v,sat}(T) - P_l = \frac{2\sigma}{R_b}\left(1+\frac{\rho_v}{\rho_l}\right)$$

Clapeyron Eqn.

$$\frac{dP}{dT} = \frac{h_{lv}}{T\left(\frac{1}{\rho_v}-\frac{1}{\rho_l}\right)}$$

$\rho_l \gg \rho_v$

Ideal gas

$P = \rho R T$

$$\frac{dP}{P} = \frac{h_{lv}}{R_g T^2}\,dT \quad \cdots (1)$$

Now, if you recall for a bubble for curved bubble basically, this if you recall, your old notes, you will see that the vapour pressure within a curve bubble is given by: Do you recall this particular thing? This we covered. So, all the things you can see how it comes in handy as we go on in the course. This is Rho v pv sat, different temperatures Rb Rho l.

Usually, this particular term is much, much less than 1, okay because it is less than 1. Then, this exponential now can be expanded in a series function. So, Pv = Pv sat at temperature 1 - 2 Sigma into Rho v divided by Pv sat Rb into Rho l okay, got it okay. Now, if you combine you can write Pg + Pv sat -Pl = 2 sigma by Rb,1 + Rho v by Rho l, okay.

Now, we already can make use of the Clapeyron equation which gives you basically dp by dt, if you recall hlv by T into 1 by Rho v - 1 by Rho l. Now, you know that Rho l is much, much greater than Rho v. And you can also invoke the ideal gas assumption Rho RT. So, this will give you combining all this. This will give you dp by P = hlv divided by RgT square dT. Let us call this equation 1, it will come in handy later, okay.

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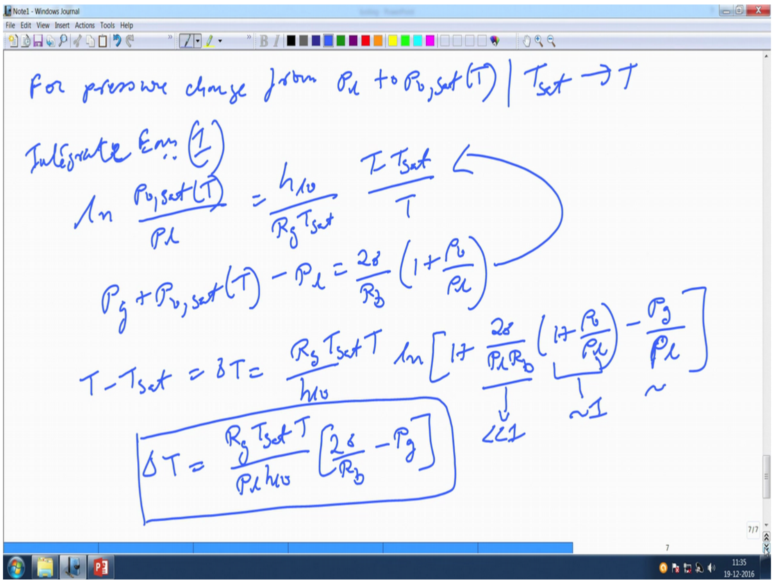

For pressure change from P_l to $P_{v,sat}(T)$ | $T_{sat} \rightarrow T$

Integrate Eqn. (1)

$$\ln \frac{P_{v,sat}(T)}{P_l} = \frac{h_{lv}}{R_g T_{sat}} \frac{T - T_{sat}}{T}$$

$$P_g + P_{v,sat}(T) - P_l = \frac{2\sigma}{R_b}\left(1 + \frac{\rho_v}{\rho_l}\right)$$

$$T - T_{sat} = \delta T = \frac{R_g T_{sat} T}{h_{lv}} \ln\left[1 + \underbrace{\frac{2\sigma}{P_l R_b}}_{\ll 1}\underbrace{\left(1 + \frac{\rho_v}{\rho_l}\right)}_{\sim 1} - \frac{P_g}{P_l}\right]$$

$$\boxed{\delta T = \frac{R_g T_{sat} T}{P_l h_{lv}}\left[\frac{2\sigma}{R_b} - P_g\right]}$$

Now, now for pressure change from Pl to Pv sat T and temperature change from T sat to T, we integrate, we integrate equation I. And we have this ln Pv sat T divided by Pl = hlv by Rg T sat T - T sat divided by T okay. Now, you already know Pg + Pv sat T - Pl = 2 sigma by Rb into 1 plus Rho v by Rho l. You substitute that over here.

Now, now it is a correct time to substitute this. What you get is that T - T sat which we take mark as delta T is Rg by hlv T sat into T, ln 1 + 2 sigma pi Pl into Rb 1 + Rho v by Rho l minus Pg by Pl I am sorry Pg by Pl, okay. So, this is the complete thing that you get. This particular term is less much, much less than 1. This is of the order of, sorry, not this particular term once again, not just this term okay.

This particular term only this one is much, much less than 1. This particular term over here is almost equal to 1 because Rho v by Rho l is a very small number, okay. So, what you get is that delta T = Rg T sat into T divided by Pl into hlv to sigma by Rb - Pg okay. Now, this is the important expression.

It is the degree of superheat that is required, okay. Then, we will we will find out a few more things about it. Like for example, what will be the critical droplet diameter, critical bubble diameter?

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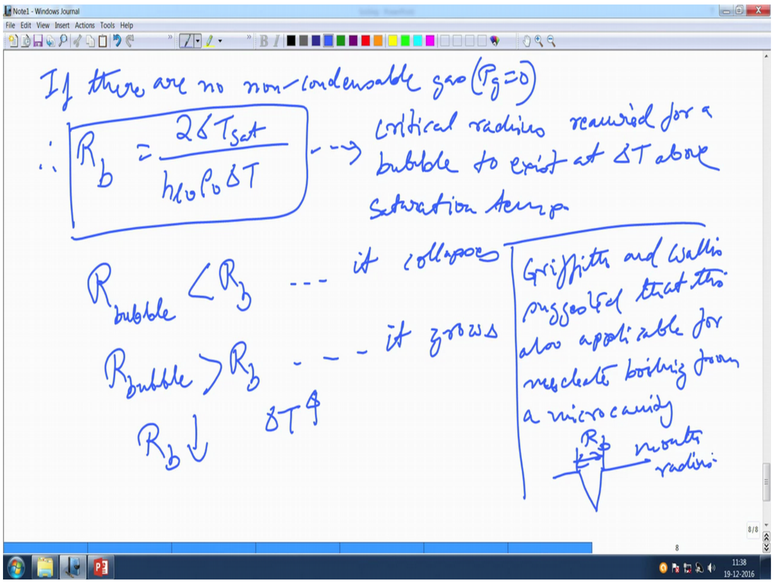

If there are no non-condensable gas ($P_g = 0$)

$$\therefore \boxed{R_b = \frac{2\sigma T_{sat}}{h_{lv} \rho_v \Delta T}} \dashrightarrow$$ critical radius required for a bubble to exist at ΔT above saturation temp.

$R_{bubble} < R_b$ --- it collapses

$R_{bubble} > R_b$ --- it grows

$R_b \downarrow \quad \Delta T \uparrow$

Griffith and Wallis suggested that this also applicable for nucleate boiling from a microcavity

R_b mouth radius

So, if there are no condensable, if there are no non-condensable phases, condensable gas that means, your Pg = 0 okay. You can cast Rb, okay which is the critical. We will define it just shortly 2 sigma into T sat divided by hlv into Rho v into delta T. So, this is the expression that you get.

This is the critical radius required for a bubble to exist at delta T above the saturation, okay. If R bubble is less than Rb it collapses; if R bubble is greater than Rb, it grows one other thing to mention is that Rb becomes actually smaller as delta T goes up. That you can see from the inverse relationship that you have that with increase of degree of superheat the critical droplet sizes also critical bubble sizes also grows up, okay.

Now Griffith and Wallace what they suggested was that. So, this is for homogenous, right. Griffith And Wallace, Wallace actually suggested, that suggested that this is also applicable and this is also applicable for Nucleate boiling, Nucleate boiling from a surface from a micro-cavity, okay. In that particular case this Rb is given by the cavity opening the mouth of the cavity. It is basically the mouth radius or diameter whatever you call it, got it okay.

So, that is an interesting argument that was provided, okay. That why does, how does a bubble actually, how does a bubble immersed in a liquid of its own kind essentially, how does it actually grows. And this also gives you and significant analysis that what it can actually show, okay. So, let us see. So, we have done this particular portion on this bubble.

Here, there is a one interesting thing that we would like to point out. So, this is for example, from a crack tip, how does a bubble growth that we have already specified over here? Now if the interface with if we consider k as the curvature of a liquid vapour interface, the curvature of liquid vapour interface, okay now, if K increases with increase in vapour volume so, it is the curvature of the liquid vapour interface, okay.

So, just take a look at this particular curve, right. So, if K increases, okay wait, increase vapour volume say, if the vapour volume is V, if that increases and K increases then, we call that this is a stable, okay. But, so, it is for example, between a to d, you can see this particular curve which is basically the curvature versus the volume, this is an increasing function. So, it is stable right, okay. Nucleation happen when K actually goes down, as V goes up.

So, in this particular regime or this particular regime, of this particular regime when K actually goes down, that is the curvature of the liquid vapour interface actually goes down with increase in volume, that is the time when you start to have nucleation, okay beyond the point d where the curve after the curvature reaches its max, right.

So, in these cases, if that is the case again moving on to this, that is the case.
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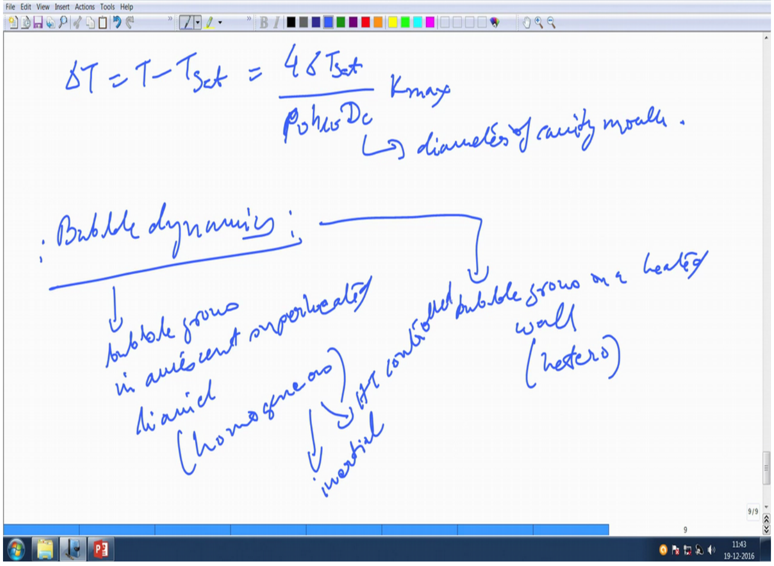

$$\Delta T = T - T_{sat} = \frac{4\sigma T_{sat}}{\rho_v h_{lv} D_c} K_{max}$$

D_c → diameter of cavity mouth.

Bubble dynamics:

- bubble grows in quiescent superheated liquid (homogeneous)
  - inertial
  - HT controlled
- bubble grows on a heated wall (hetero)

Then this delta T is written as T - T sat = 4 sigma T sat divided by Pv hlv into Dc into K max. This is the diameter of the cavity mouth, okay. So, that is what the, the key significance that we have, okay. So, now in the, in the next thing is that now, that we know, that what the bubble does?

Let us look at the bubble dynamics. Now, we know how a bubble can actually form. So, we can look at the bubble dynamics in two ways. In one case the bubble grows, grows in quiescent superheated liquid. That is what we did just a moment ago, right I mean it which we established what is the critical diameter. And the bubble grows on a heated wall. So, this is homogeneous nucleation.

This is hetero, okay. So, we are going to study this particular thing in details now, okay. So, that we can see that what is actually going on, okay? So, in the next lecture, what we are going to do is that, we are going to look at this particular phenomena in more details, okay. And we are going to see that there will be. First, we will take the homogeneous nucleation situation.

And we are going to see that there are two basically growth phase: one is inertial okay and the other one is heat transfer controlled. So, you will see what each of those phases actually looks like, okay. So, we will see in the next class and see that how we proceed from there, okay, thank you.