Multiphase Flow
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Lecture No. # 34
Heat Transfer in Different Regimes of Boiling

Good morning everybody. Today, we are going to start or going to discuss heat transfer in different regimes of boiling. So far, basically, we have seen the dynamics of vapor bubble and mainly the dynamics of vapor bubble on a heated surface – how does the nucleation takes place; how does a bubble grow; and, ultimately, how does it depart and what is its effect on the total process of boiling; that we have discussed. So, those discussions are important. Basically, they form the ground work for developing any sort of heat transfer model, which is used for the prediction of boiling heat transfer.

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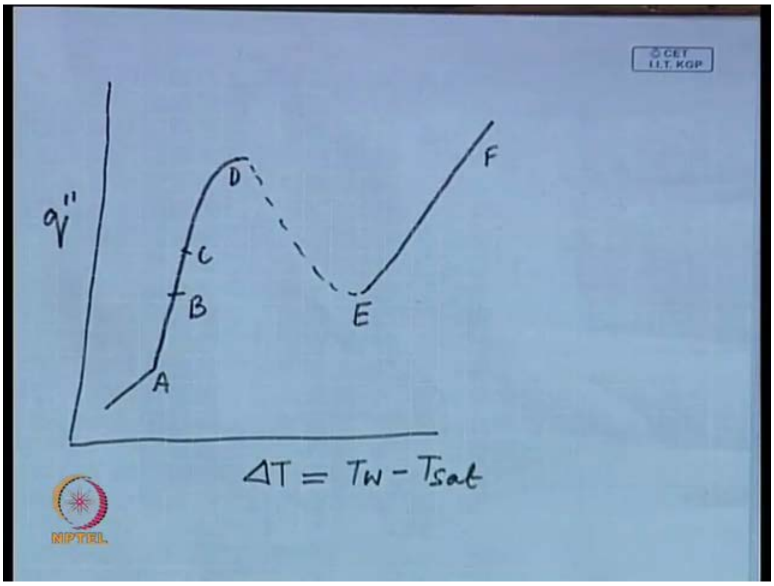

Now, already I have pointed it out earlier; and, this is a very basic thing that we have got in a boiling curve. This is delta t; that means, T w minus T saturated. And, this side is heat flux. So, in the boiling curve, we have got different regimes of boiling. By a heat flux controlled experiment, we will get only the portions shown by the form line; that means, we will get the nucleate boiling and we will get the film boiling region; transition boiling – we may not be that successful in getting it.

In the nucleate boiling and film boiling region, what we can find that again there are different regimes of boiling, which do not follow the same laws or same mechanism of heat transfer. Like as I have mentioned earlier, we have got isolated region of boiling; let us say the inception of boiling is at point A; A to B is the isolated bubble region or partial nucleate boiling region. Then, we will have a transition from the partial nucleate boiling region to the region of columns and slugs.

Then, we will have… Let us say this is C. Then, we will have up to D, the fully developed nucleate boiling region. And, at D, we will have the critical heat flux. D to E is the transition boiling region. And, at E, we will have inception of film boiling. And, the heat flux related to E is known as the minimum heat flux for film boiling. Then, heat wave; we will have radiation. So, basically, we can have some sort of models from A to B; then, probably, the mechanism will be different from B to D. At D, people have… This is the critical heat flux region. So, people have postulated different mechanisms of heat transfer for the point D. D to E – this region is transition boiling region; I mean till today, it is not very well-known what is the exact mechanism of heat transfer during the transition boiling regime. So, we do not have many models for the region B to E.

But, E to F is the film boiling region (Refer Slide Time: 04:14). And, here again models are available. What I mean to say, from engineering point of view, the discussion, which we will have today or after this also, in this lecture and later on also, those are very important, because the estimation of heat transfer coefficient is necessary for the analysis of boiling heat transfer, for the design of boiling equipment, for the safety of nuclear reactor system. So, this discussion, which we will continue or which we will start today is very relevant. As far as industry is concerned, most of the application of boiling heat transfer will be within the region A to B; that means, within the region of nucleate boiling. So, obviously, people have given more emphasis to nucleate boiling.

Transition boiling is a very dissipative area people want to avoid it. So, we will not have much; I mean we will also not do much discussion on this. Point D is very important, because it indicates the termination of nucleate boiling. We should discuss it in detail. And then, E to F film boiling – though we do not desire this mode of boiling in most of the equipment, but some analysis for this is also available and sometimes that may be needed. So, we will start from the isolated bubble region.

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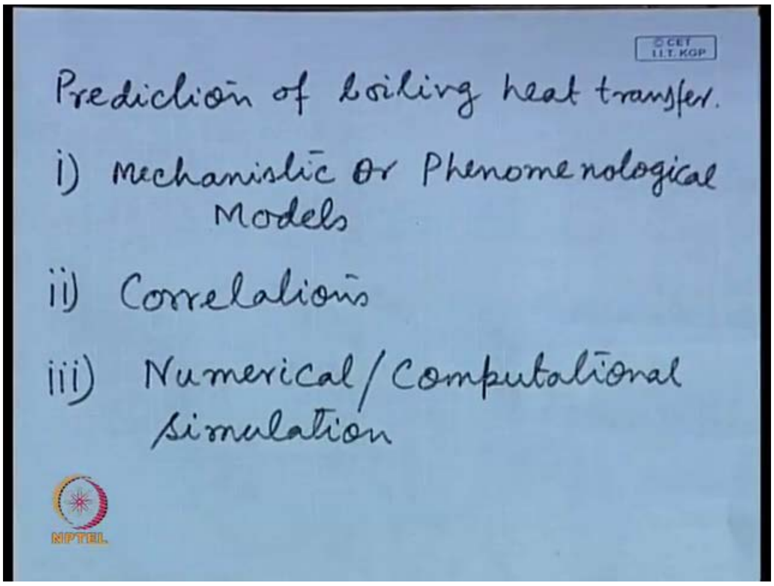

Prediction of boiling heat transfer.

i) Mechanistic or Phenomenological Models

ii) Correlations

iii) Numerical/Computational simulation

Now, if I see the modeling approach; or, rather if we call it prediction of boiling heat transfer, there are two approaches: the first approach is known as mechanistic or phenomenological models; second approach – correlations; third one, which is emerging very fast, but still it has to go a long way before it is a regularly used for the industrial design; that is the numerical or computational simulation. Our discussion will be restricted to the first two points; that means mechanistic or phenomenological models and correlations. Now, you see mechanistic or phenomenological models are superior in the sense they give us the physics behind the phenomena. And, based on the physics only, these models are developed. But, they have got their limitations also.

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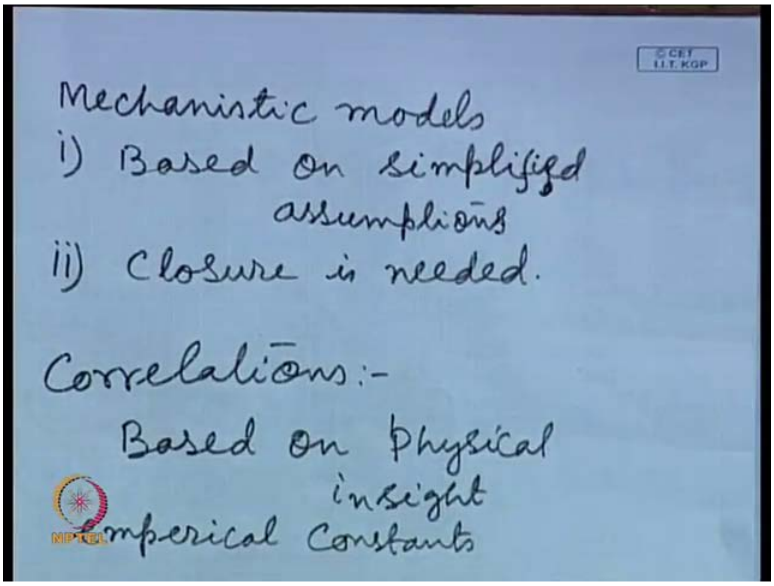

Mechanistic models
i) Based on simplified assumptions
ii) Closure is needed.

Correlations:-
Based on physical insight
Emperical Constants

Let us put the limitations. Mechanistic models – the limitations are based on simplified assumptions. All mechanistic models… Any model that will have some sort of a set of assumptions; based on that, the models are developed. So, mechanistic models based on simplified assumptions. So, this is one drawback of the mechanistic model. And, many cases in the mechanistic model what we do that as we assume certain thing; that simplified assumptions. So, closure is needed. Due to this assumption, all the information from the same model does not come. So, we have to use some other closure relationship, constitutive relationship to close the model.

I can give some examples; and, where we are having difficulty I can also give those examples. You see for bubble growth or bubbling process the mechanistic model if we use, then what we are doing, we are assuming the bubble shape to be spherical or to be hemispherical. But, the actual bubble shape could be different. Then, we are assuming isolated bubbles; and, we are assuming that two neighboring bubbles will not interact with each other. So, this is also assumption, which is not valid in actual case. Then, let us say, regarding the nucleation site, which is very dependent on the surface – the manufacturing process of surface, the contamination, the scaling process, fouling, etcetera. So, this is some sort of time bearing attribute of the surface. And, this is something, which is statistical in nature, stochastic in nature. So, by mechanistic modeling, it is also difficult to take care of this type of factor.

Then, you see the bubble departure. The bubble departure – we analyze based on some sort of force balance. And, these forces are static forces acting on the bubble. So, the effect of liquid velocity, etcetera are not considered in a very rigorous manner. So, you see that assumption is also not fully valid. So, that is why, mechanistic model has got their limitations. But, even then, mechanistic models are done; they are corrected also. Once they are done, these mechanistic models are constructed. They can be compared with experiment. And, if we see that there is large discrepancy, then one can correct those mechanistic models. So, these models are done and used. But, people also go for correlation kind of prediction. Now, the type of correlations I will discuss, they are not very blind black box kind of correlation. Again a correlation will be successful if the basic physics is reflected in the correlation. So, they are based on physical insight. So, that is why, it is not totally black box kind of correlation. And, they will have of course empirical constants.

Now, as far as the analysis of boiling heat transfer is concerned, we really cannot differentiate between mechanistic model and correlation. We can see more or less a mixed kind of approach. And, let us see what the different models available for boiling heat transfer are.

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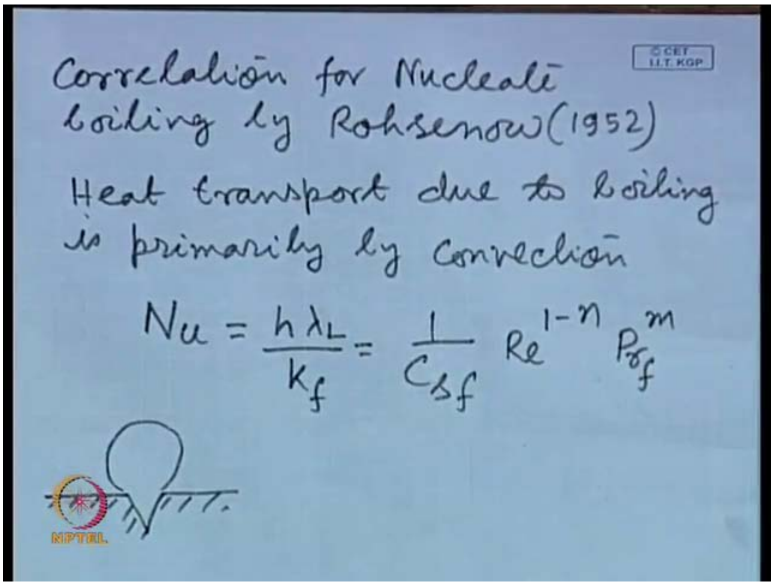

Correlation for Nucleate boiling by Rohsenow (1952)

Heat transport due to boiling is primarily by convection

$$Nu = \frac{h\lambda_L}{k_f} = \frac{1}{C_{sf}} Re^{1-n} Pr_f^{m}$$

The most common, most widely used correlation is due to Rohsenow; correlation for nucleate boiling by Rohsenow (1952). He was a professor at MIT. Now, what has been postulated in this correlation is that the process of boiling which takes heat from a heated surface is similar to the convection process. So, if it is similar to the convection process, then… So, let ne write, heat transport due to boiling is primarily by convection. So, if this is by convection, then the log of convection should be applicable to boiling heat transfer also. And then, one can define Nusselt number that is equal to h lambda L by K L or K f. And, that is equal to one by C s f R e to the power 1 minus n and P r f to the power m. So, let me tell you, by this time probably, you have also understood that for liquid either we are using a subscript A for L. So, this is the very well-known formula for Nusselt number.

So, basic definition of Nusselt number is the convective heat transfer coefficient multiplied by some characteristic link divided by the conductivity of the fluid. This is dependent on Reynolds number and Prandtl number. So, 1 by c s f is some sort of a coefficient; then, R e to the power 1 minus n; and, Prandtl to the power m. And Prandtl number is defined based on liquid properties, because whenever… The basic idea here is we have got a solid surface. In the solid surface, we have got cavity. From the cavity, a bubble will generate. When this bubble will move, it will create some sort of convection current. And, the convection relationship is given by this particular formula.

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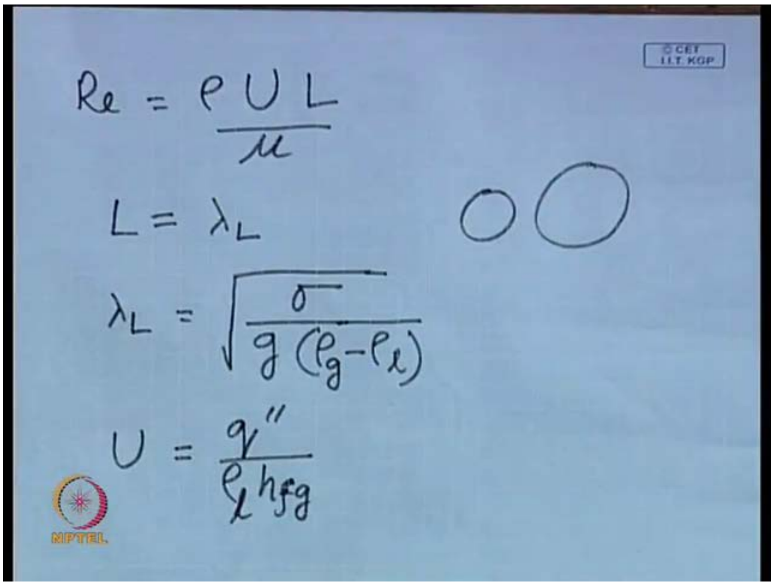

$$Re = \frac{\rho U L}{\mu}$$

$$L = \lambda_L$$

$$\lambda_L = \sqrt{\frac{\sigma}{g(\rho_g - \rho_l)}}$$

$$U = \frac{q''}{\rho_l h_{fg}}$$

Now, problem is p r f – there is no difficulty; depending on liquid property we can calculate the Prandtl number. But, what about Reynold’s number? How can we calculate the Reynold’s number. So, Reynold’s number R e will be some sort of rho and then velocity and then some sort of length parameter by viscosity. So, how this thing can be taken? Particularly, how can we define the velocity and the length parameter? Already if you see the previous equation, here (Refer Slide Time: 17:13), for the Nusselt number, we have to take a characteristic length. So, probably, L could be replaced by that characteristic length lambda L. And. this lambda L is what? Physically, it is what? Before constructing this model, people have done number of experiments. Now, what people have seen that the boiling heat transfer really does not depend on the physical dimension. What do I mean to say that suppose if you take some sort of circular cylinder and on the circular cylinder, you have got some sort of boiling heat transfer, you get another circular cylinder of larger diameter.

Now, if the boiling heat transfer, it is very difficult to get a direct correlation shape between the boiling heat transfer and the diameter; or, let us say, if we take some other dimension of the physical system, it is difficult to get a good correlation between boiling heat transfer and the physical dimension. So, definitely, this kind of diameter or let us say the internal diameter of a tube – that does not become the characteristic length in a boiling heat transfer process. So, it has to do something with the bubbles, because those bubbles are very important for the transport of heat. So, that is why, it has been defined like this.

Already we are familiar with this (Refer Slide Time: 18:59) kind of expression, sigma by g rho v or rho g – gas and minus rho l or rho f. So, this is how the length parameter is defined. Then, how the U is defined? U can be defined, the velocity; the velocity can be defined like this. You see there will be some heat flux given; and, depending on the heat flux, more the heat flux, the more will be the heat transfer. So, that means, the heat flux has got a direct relationship with the velocity. So, people have tried to use this (Refer Slide Time: 19:52) kind of a relationship that q by rho h f g. See this kind of a relationship if you use, rho l, this gives the velocity of the mass generated due to evaporation. So, more the heat flux, more will be the velocity. And, this can be taken as the characteristic velocity for your prediction of boiling.

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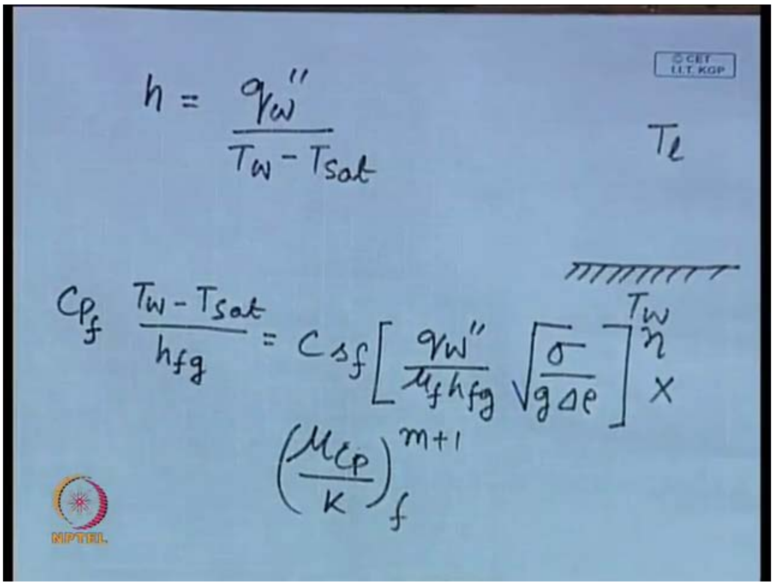

$$h = \frac{q_w''}{T_w - T_{sat}}$$

T_l

T_w

$$C_{p_f}\frac{T_w - T_{sat}}{h_{fg}} = C_{sf}\left[\frac{q_w''}{\mu_f h_{fg}}\sqrt{\frac{\sigma}{g\Delta\rho}}\right]^{n} \times \left(\frac{\mu c_p}{k}\right)_f^{m+1}$$

Now, along with this, one can also define h is equal to heat transfer coefficient, that is, q w by T w minus T sat. This is again another important point, which I need to discuss; that in a boiling experiment, that you can have the wall heated; the wall is at a temperature T w; the bulk of the fluid – this is at a temperature T l. Now, this T l need not be equal to the saturation temperature. T l could be a temperature below the saturation temperature; it could be at the sub-cooled condition. Now, even then, it has been seen that it does not depend much on the degree of sub-cooling. Rather, if we get a correlation between h and T w minus T sat for the case of moderate sub-cooling, it gives a very good correlation. So, that means, it is not that much dependent on the actual temperature of the bulk of the fluid; rather, it is dependent on the temperature difference T w minus T saturated. So, that is why, in boiling curve also, we have represented it by T w minus T sat. And, in most of the boiling correlations or model, the delta T will be T w minus T sat. So, you see, this is how we can define basic definition of… Basic definition of heat transfer coefficient can be obtained like this.

Now, putting all these things together, one can have (Refer Slide Time: 22:19) C p f or l, that is, the liquid side; T w minus T sat by h f g. This is the latent heat of vaporization. Again, I am telling, f represents the liquid and g represents the vapor. So, this is equal to C s f within bracket q w by mu f h f g square root of sigma by g into del rho to the power n – this multiplied by mu C p by k determined at the fluid temperature m plus 1. So, last term, you can see, this is related to Prandtl number. So, this is how we will get the relationship for the boiling heat transfer. If you see the relationship, you can see that here we are getting a very straightforward relationship between heat flux and the wall super heat T w minus T sat. So, if this relationship is correct and applicable for the range of nucleate boiling… So, part of the boiling curve you can construct with this relationship.

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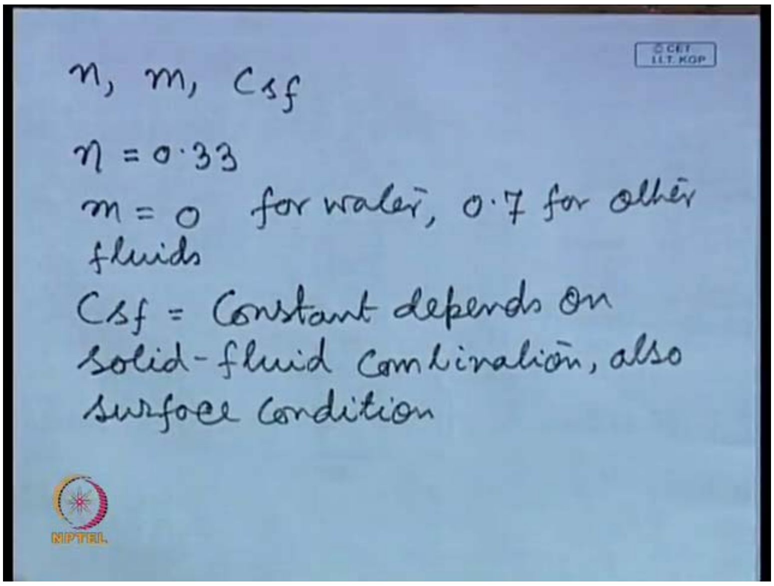

n, m, C_{sf}

$n = 0{\cdot}33$

$m = 0$ for water, $0{\cdot}7$ for other fluids

C_{sf} = Constant depends on solid-fluid combination, also surface condition

And, the unknown quantities what are there in this particular equation are n, m and C s f. So, these three factors are very important – n, m and C s f. Now, n is typically taken as 0.33; n is equal to 0.33; m is equal to 0 for water and 0.7 for other fluids. Generally for aqua system and water, m is taken equal to 0; and, it is 0.7 for other fluids. Then, C s f – some sort of empirical constant depends on solid-fluid combination and also surface condition. So, there is a very long list, how C s f will vary on different solid-liquid combination.

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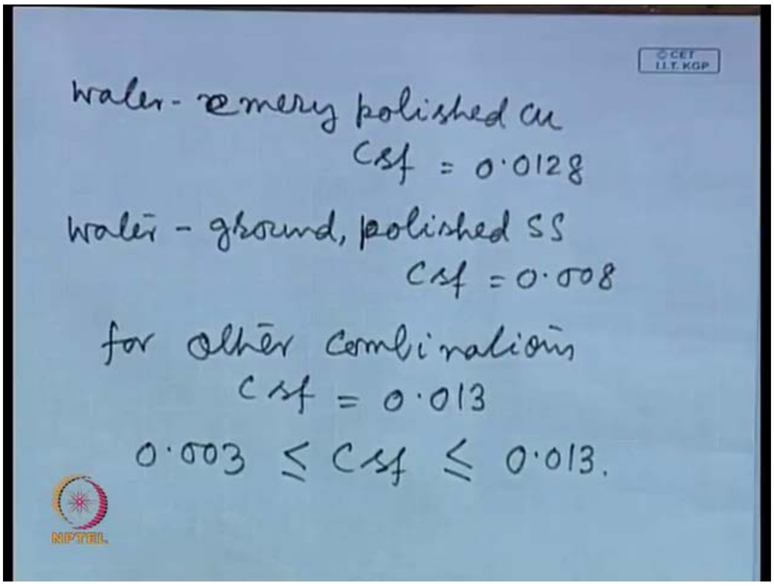

water - emery polished cu

Csf = 0·0128

water - ground, polished SS

Csf = 0·008

for other combinations

Csf = 0·013

0·003 ≤ Csf ≤ 0·013.

For example, suppose we have got a combination of water and emery polished cu – copper; so, C s f will be 0.0128. And, let us say, we have got water and let us say ground and emery polished SS – stainless steel. So, C s f will be 0.008. So, you see that there is a range of C s f within which it varies; we will have a list of liquid and solid combination for which C s f is given. So, sometimes you may encounter a liquid-solid combination, which is not there in the list. So, for those kinds of combinations, it is recommended… For other combinations, C s f is equal to 0.013. So, basically, you will see that the value of C s f varies from 0.003 to 0.013.

What has been done that for unknown fluid, higher value has been predicted. Assuming that for the higher value, you will predict a higher heat flux; and, the design will be on the safer side. But, the discretion or the decision depends on you. So, you can take a decision depending on the design application. So, this is the Rohsenow correlation. Rohsenow correlation is very famous and very widely used; even today, it is very widely used for many design calculations. And, it gives reasonably good prediction. What is reasonably good? Probably, you will be bit surprised to know that it predicts boiling heat transfer in most of the cases within 100 percent. In case of boiling heat transfer, this kind of prediction is called (( ))

Boiling heat transfer – so many intricate phenomena are involved and heavy accurate prediction is almost impossible. So, 20 percent or 30 percent prediction is assumed to be accurate. And, what I have told for Rohsenow correlation, 100 percent; within 100 percent accuracy, it is calculating. So, that is called a good or very good prediction. Now, what is the reason of success, this is a good success? We may feel bit awkward, because we are familiar with a much higher accuracy of prediction in other cases. But, in case of boiling heat transfer, this is a good success. And, people say that the root of the success lies in C s f.

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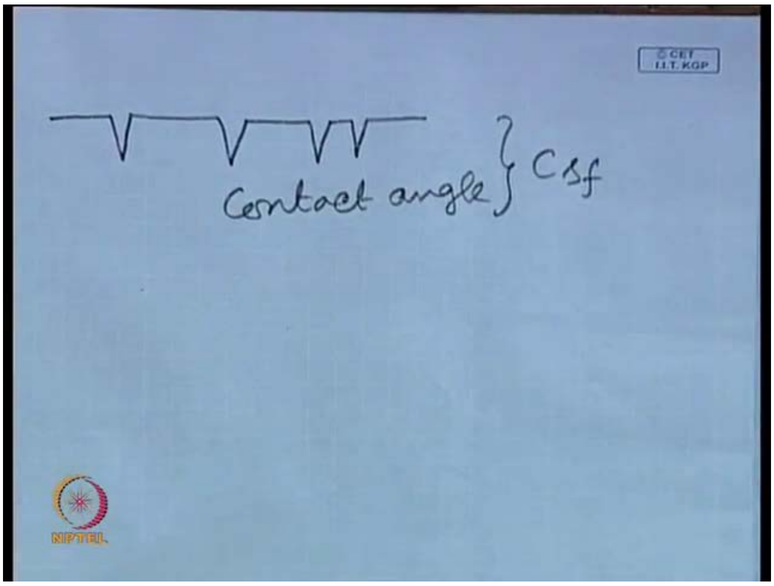

This C s f takes care of many stochastic variables in the process of boiling; that means, depending on the surface and the liquid combination and surface roughness or surface preparation, there could be different nucleation sites; there could be contact angle. The contact angle thing is not directly appearing in the correlation. So, there could be effect of contact angle. So, all these things – these kinds of distribution and then contact angle are taken care of by C s f. Actually, Rohsenow has done a very… With a very good foresight, he has made this correlation. And, with the help of C s f – there are large number of C s f values tabulated, one can get reasonable prediction of boiling heat transfer.

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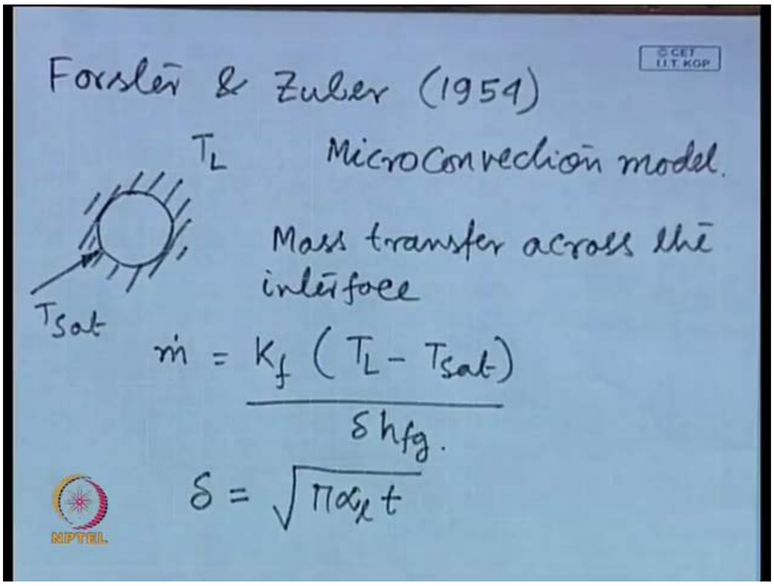

Forster & Zuber (1954)

Microconvection model.

Mass transfer across the interface

$$\dot{m} = \frac{K_f (T_L - T_{sat})}{\delta h_{fg}}.$$

$$\delta = \sqrt{\pi \alpha_l t}$$

Now, we will go to another correlation of boiling heat transfer. That correlation is much similar to the correlation of Rohsenow, but there is some difference. That correlation is given by Forster and Zuber almost at the same time; it is in the year of 1954. Now, Forster-Zuber correlation – it assumes that there is a bubble in a super heated bulk of liquid. And, this bubble is small bubble and the motion of the bubble that creates convection. So, sometimes it is called microconvection model.

The microconvection model… Let us say the bubble is growing due to evaporation. What will be the mass flow rate or mass transfer? Mass transfer across the interface we will get; m dot is equal to K f T L minus T saturated divided by delta into h f g. Now, this is T L (Refer Slide Time: 33:04) – the temperature of the bulk fluid; and, the interface temperature is T saturated. Delta is some sort of a film thickness or boundary layer thickness. And, we have already seen, by the transient conduction analysis, delta can be scaled like this – pi alpha L – alpha is the thermal diffusivity of the liquid – and, t – time. So, this is how the delta can be scaled from our transient conduction equation.

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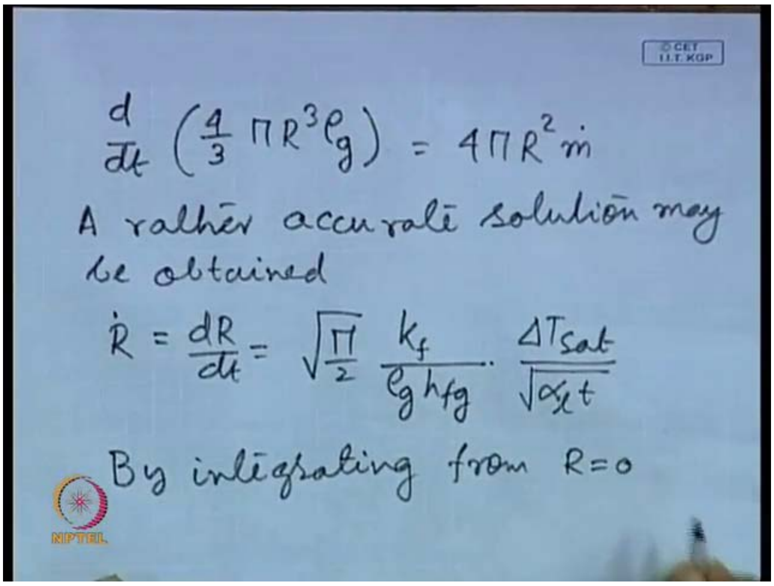

$$\frac{d}{dt}\left(\frac{4}{3}\pi R^3 \rho_g\right) = 4\pi R^2 \dot{m}$$

A rather accurate solution may be obtained

$$\dot{R} = \frac{dR}{dt} = \sqrt{\frac{\pi}{2}}\,\frac{k_f}{\rho_g h_{fg}} \cdot \frac{\Delta T_{sat}}{\sqrt{\alpha_l t}}$$

By integrating from $R=0$

Using this basic information, one can write some sort of a relationship like this – d by d t of four-third pi R cube rho g; that is equal to four pi R square m dot. So, basically, this is relating the rate of mass transfer and rate of bubble growth. Now, following this logic or refining it, a rather accurate solution may be obtained; R dot – that is equal to d r by d t; that is equal to root over pi by 2 into k f – the thermal conductivity of the liquid – by rho g h f g – the density of the vapor and the latent heat of vaporization – then, delta T sat by alpha l t. With this, the above equation can be integrated.

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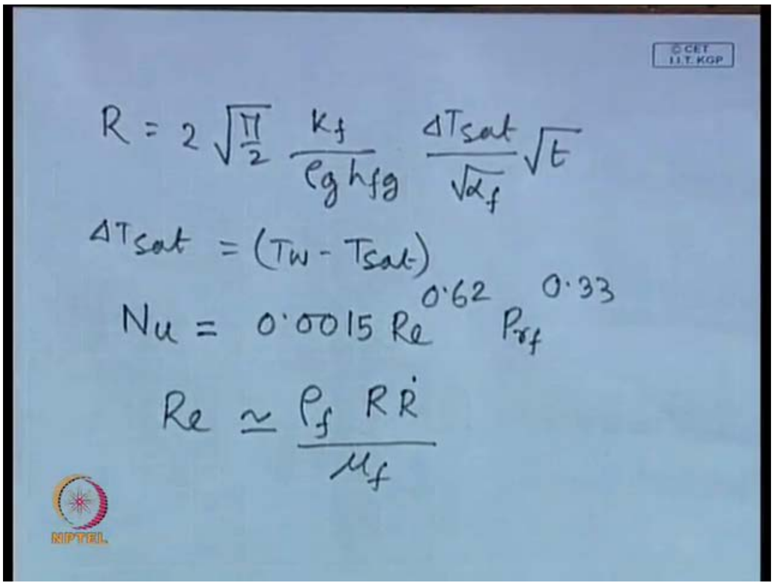

$$R = 2\sqrt{\frac{\pi}{2}}\,\frac{k_f}{\rho_g h_{fg}}\,\frac{\Delta T_{sat}}{\sqrt{\alpha_f}}\sqrt{t}$$

$$\Delta T_{sat} = (T_W - T_{sat})$$

$$Nu = 0.0015\, Re^{0.62}\, Pr_f^{0.33}$$

$$Re \simeq \frac{\rho_f R\dot{R}}{\mu_f}$$

By integrating from R is equal to 0 at t is equal to 0, what we can get, R is equal to 2 root over pi by 2 into k f by rho g h f g into delta T sat by root over alpha f into root over t. So, this is how this form of equation is not very unfamiliar to us. So, we will get how the R is changing. So, bubble radius, some sort of a relationship from bubble growth we will get. Similar relationships we have derived earlier. Now, delta T sat again is given by T w minus T saturation. Once we have got it, let us go back to our generic convection equation.

In a convection equation, Nusselt number is given by (Refer Slide Time: 37:02) 0.0015 R e to the power 0.62 into P r f to the power 0.33. This is the relationship between Nusselt number, Reynolds number and Prandtl number. R e – Reynolds number – that can be approximately told as rho f R R dot by mu f. So, what I have taken? Here I have taken for the velocity dr by dt; I have taken that scalewise, the velocity scale is proportional to dr by dt; that is what I have assumed. And, the length scale – I have taken as the radius of the bubble. So, Reynolds number can be estimated by this particular formula.

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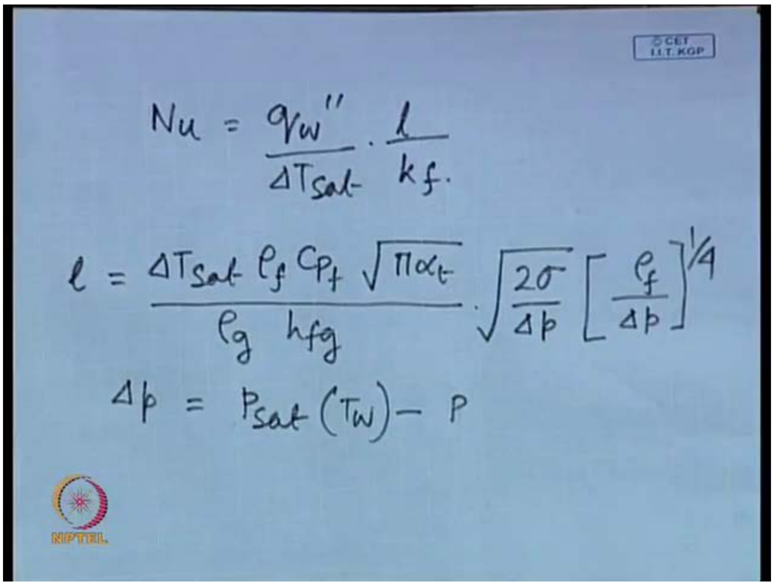

$$Nu = \frac{q_w''}{\Delta T_{sat}} \cdot \frac{l}{k_f}.$$

$$l = \frac{\Delta T_{sat}\, \rho_f\, C_{P_f} \sqrt{\pi \alpha_t}}{\rho_g\, h_{fg}} \cdot \sqrt{\frac{2\sigma}{\Delta p}} \left[\frac{\rho_f}{\Delta p}\right]^{1/4}$$

$$\Delta p = P_{sat}(T_w) - P$$

Nusselt number again can be estimated – q w by delta T sat into l by k f. So, basically, it is heat transfer coefficient – the first term; then, there is a length scale divided by the conductivity of the fluid.

Now, length scale actually has been done in a very typical manner by Forster and Zuber. For the Reynolds number calculation or estimation, we have taken simply R. But, for the length scale calculation for Nusselt number, what they have done? They have done some sort of a different methodology. And, they got l is equal to delta T saturated rho f C p f root over pi alpha T – this is a lengthy expression – by rho g h f g – then, root over 2 sigma by delta p and rho f by delta p whole to the power 1 by 4. So, this is what they have got for the length scale calculation. Now, delta p to r means coming. Delta p is equal to nothing but p saturated at wall temperature minus the P liquid. So, this is how delta p is calculated.

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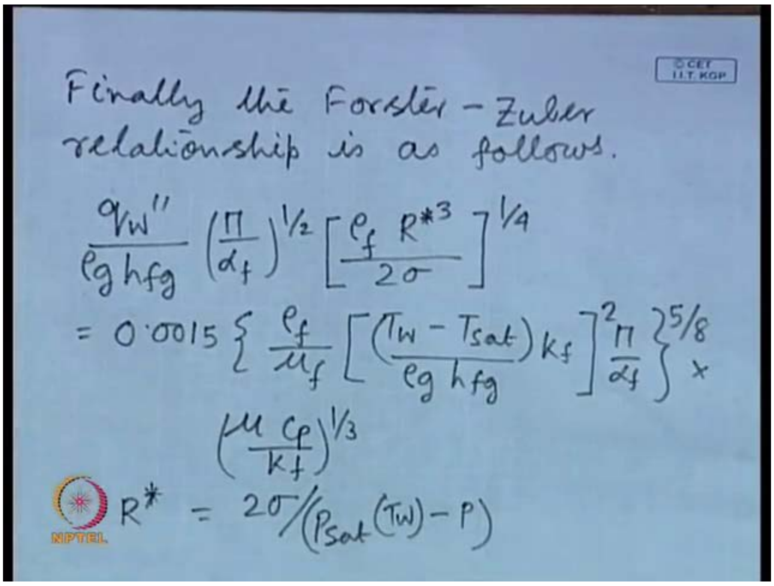

Finally the Forster-Zuber relationship is as follows.

$$\frac{q_w''}{\rho_g h_{fg}}\left(\frac{\pi}{\alpha_f}\right)^{1/2}\left[\frac{\rho_f R^{*3}}{2\sigma}\right]^{1/4} = 0.0015\left\{\frac{\rho_f}{\mu_f}\left[\left(\frac{T_w - T_{sat}}{\rho_g h_{fg}}\right)k_f\right]^2\frac{\pi}{\alpha_f}\right\}^{5/8} \times \left(\frac{\mu c_p}{k_f}\right)^{1/3}$$

$$R^* = 2\sigma/(P_{sat}(T_w) - P)$$

Now, whatever I have done, with this, if I now consolidate the formula, I will get – finally, the Forster-Zuber relationship is as follows. What is this relationship? See this relationship is like q w by rho g h f g into pi by alpha f to the power half into rho f R to the power star 3 by 2 sigma to the power 1 by 4 – equal to 0.0015 within brackets e f by mu f within brackets T w minus T sat by rho g h f g into k f whole square into pi by alpha f whole to the power 5 by 8 into mu c p by k f to the power one-third.

And, R star – that is equal to twice sigma by P saturated T w minus P. So, this is a very lengthy correlation. But, it is comparable to the previous correlation, which we have got due to Rohsenow. There are a few differences. First difference is that here (Refer Slide Time: 42:25) in the Rohsenow correlation if you remember, there was a term called C s

f. Now, that term C s f… This is the Rohsenow correlation (Refer Slide Time: 42:41). This Rohsenow correlation – we had a term C s f. And, this term C s f is not determined by some theory, but we have got mainly from experiment. And, this C s f values are tabulated or listed for different solid-fluid combination.

In this case also, there is (Refer Slide Time: 43:05) some sort of a numerical constant 0.0015. But, this has come from the derivation itself; this is not plugged in from some other source. But, again, C s f has got some sort of a physical meaning that it is dependent on the solid-liquid combination. It takes care of the waiting property of this solid like your contact angle; it takes care of the activated nucleation sites on the solid surface. But, in this case, it does not have any sort of physical meaning. And, in this case, the solid characteristics we are ignoring. But, even then, due to the functional nature, due to the parameter, which are involved in this correlation, this correlation moderately predicts the boiling heat transfer over a good range for a number of fluids. So, that is the advantage.

Now, the problem with this model or the Rohsenow model is that this q is directly proportional to delta T. Now, q – heat flux is proportional to delta T. This seems very logical. But, there is one difficulty that during experiment, as I have already mentioned that if you provide q and delta T w, some sort of a relationship, that delta T w should be T w minus P saturated, not the actual temperature of the bulk of the fluid. So, this is one controversy, which the engineers or scientists could not resolve very easily; they took time to resolve this thing. This is one of the drawbacks of these two correlations.

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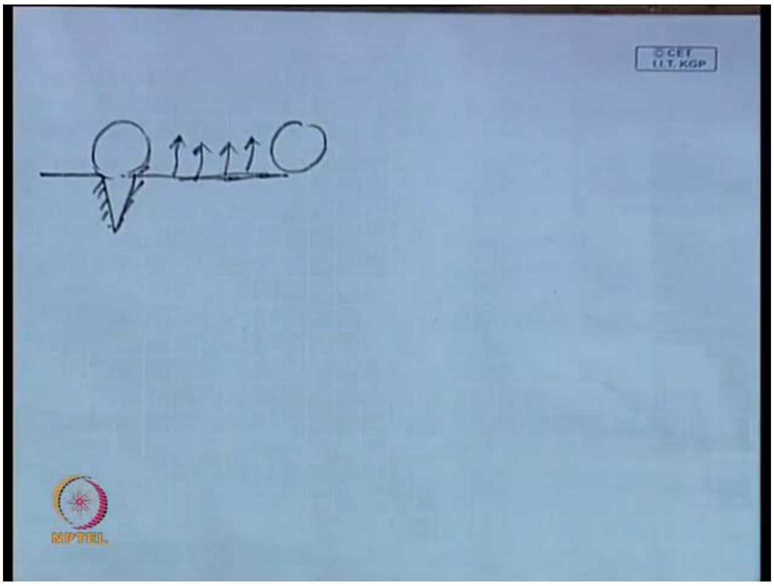

Another drawback of these two correlations is like this. Both of the correlations – they are based on the motion created by the bubble and some sort of convection generated due to this. Now, what happens? There are two bubbles. But, in between also, there is some fluid; there is some sort of fluid to solid contact. So, here also, there will be some amount of heat transfer. So, this part has not been taken in cognition in these two models. And, another thing what happens that the bubble heat transfer when we think of, definitely, the latent heat or h f g is very important. But, at least at the initial stage of the boiling process, again, some people have pointed out that the heat transfer due to the transfer of latent heat is only a portion of the total heat transfer; it is not taking care of the entire amount of heat transfer. So, these models – that is why are complete models. So, there have been criticisms. So, as there is criticism, people have then suggested other models for a better prediction. So, let us see what the other models possible are.

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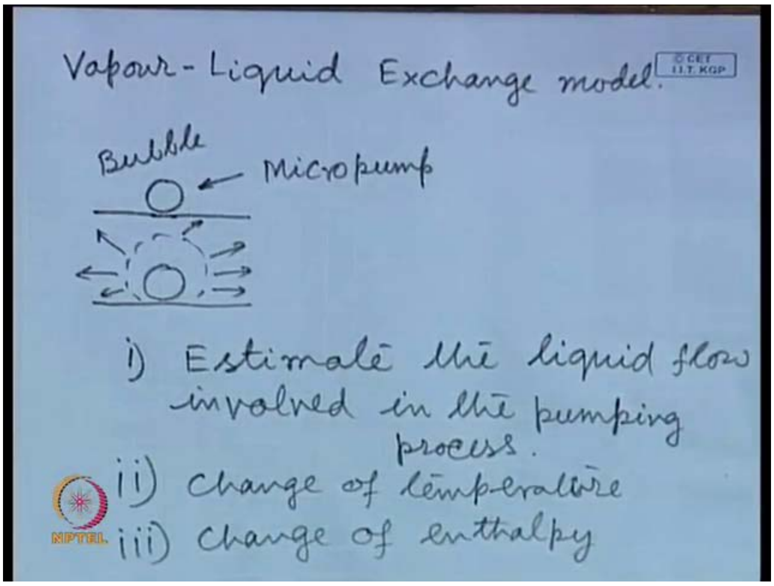

Vapour-Liquid Exchange model.

i) Estimate the liquid flow involved in the pumping process.
ii) Change of temperature
iii) Change of enthalpy

Now, the other models – there are many models for nucleate boiling. But, the other model, which I think will be of some interest to you and it shows a different kind of approach can be termed as vapor-liquid exchange model. The vapor-liquid exchange model – it is assumed that a bubble… Let us say there is a bubble maybe on the wall, maybe just above it. This is a bubble – it is nothing but a micro pump. So, when the bubble… Let us say the bubble somehow collapses; or, when the bubble leaves this particular surface; so, what it is doing? If it is living this particular surface, then it is living some sort of a void; or, if it is collapsing, it is creating some sort of a void. So, the fluid will rush towards this point – towards the point where the bubble was there.

And then, let us say the bubble is growing. If the bubble is growing, it will push the fluid in the outward direction. So, when the bubble is growing, it is pushing the fluid in the above outward direction; when it is departing or collapsing, it is sucking fluids towards its center. And, this kind of process keeps on… I mean this growth and departure of the bubble – that keeps on occurring during boiling. So, we will have some sort of a pumping process of liquid due to the motion of the bubble. And, this pumping process is mainly responsible for the heat transfer during boiling. So, if this pumping process is responsible for boiling, then how it can be model?

The modeling mechanism could be – first, one has to estimate the liquid flow involved in the pumping process; that is important; and then, one has to find out change of temperature of the fluid; and then, from there, change of enthalpy. This change of enthalpy is nothing but what heat is being taken from wall. So, this is how your heat transfer due to this pumping process can be estimated. So, I think we will continue it in our next class.