Thermal Operations in Food Process Engineering: Theory and Applications
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Lecture - 39
Boiling and Condensation

Good morning. So, till now we have done all the modes of heat transfer that is conduction, convection and radiation and as far as practicable we have done lot much problem solution so, that understanding becomes easy. Now, we will come to boiling and condensation, 'right'. This is also a very important thing in the heat transfer that is boiling and condensation. The greatest example we give is that when you are making tea at home, 'right', when you are making tea at home.

So, you are giving some heat to the container and after sometime that liquid that is water boils. The moment it is boil you put the tea and then you get the tea, 'right'. This is one example. Another example is that while you were boiling if you by chance put something on the top of the container then you would see that before putting that on the top of the container there was no water or nothing on there that lid. But, the moment you have put that lid on that after boiling when everything was over when you take out you see that lot of liquid coming out from the lid.

Where from it came? Those vapors came in contact with the lid and they condensed, 'right'. So, both the phenomena in heat transfer is very widely utilized and we look into the from the angle of heat transfer because this is our thermal operations in food engineering theory and applications, 'right'.

So, till now we were doing theories as well as and when we could we have given some example. So, that is what we are doing. Now, we will do with boiling and then condensation or this condensation and boiling is the our 39th lecture class, 'right'. Our lecture class is now 39th and we are coming to boiling and condensation, 'right'.

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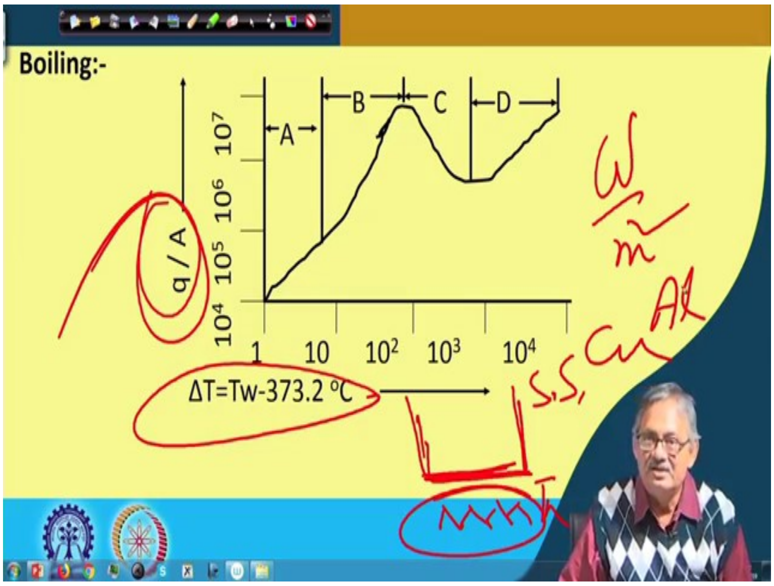

If you take graph of q/A that is heat transfer rate per unit area, 'right'. So, there is flux per unit area that is W/m^2, 'right'. If you take that versus ΔT and now this ΔT is that you have this container, 'right', you are heating by some means, 'right'. So, this has temperature T of the heater and the wall will also attain a temperature depending on the material 'right'. If it is stainless steel one, if it is copper another if it is aluminum another because the conductivity of the materials are different, 'right'.

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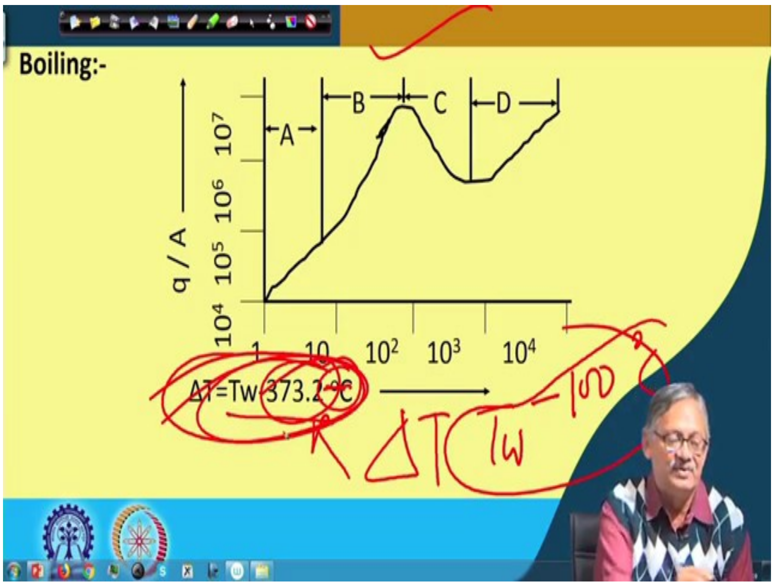

So, depending on what material you are taking that delta T will be this that is T_w minus we assume since it is under boiling. So, boiling temperature is 373.2 K, 'right'. So, T_w is 373. So, this should not be then centigrade this should be Kelvin T_w - 373.2 K, 'right' because, if it is centigrade then it should have been T_w - 100 °C because 373.2 K is 100 °C, 'right'. So, either ΔT is T_w - 100 °C or T_w -373.2 K, 'right'. Please do this correction this is Kelvin ok.

Now, if we have a plot here this is called log log plot. So, then we see that the q / A is increasing reaching a maximum then falling and then again going up, 'right'. This is the typical boiling curve again and again the ΔT is T_{wall} minus the boiling point of water that is 100 °C.

So, if we plot that versus q/A in a log log plot then we get this nature of the curve, 'right'. This nature of the curve has different zones, one is that zone A within this delta T that is between 1 to 10 almost, 'right', between 1 to 10 then between 10 to 1,000, 'right', between 10 to 1,000 this is B to C. So, rather between 10 to 100 it is B and between 100 to 1,000, it is between 100 to 1,000 it is the C that is this zone, 'right'.

Between 100 to 1,000 it is C and more than 1,000 to say 10^4 10,000 it is again D that is q/A or the flux is varying increasing in the zone A again increasing in the zone B coming to a maximum in the zone B and C junction and then dropping and the zone C, 'right' and again increasing in the zone D, 'right'.

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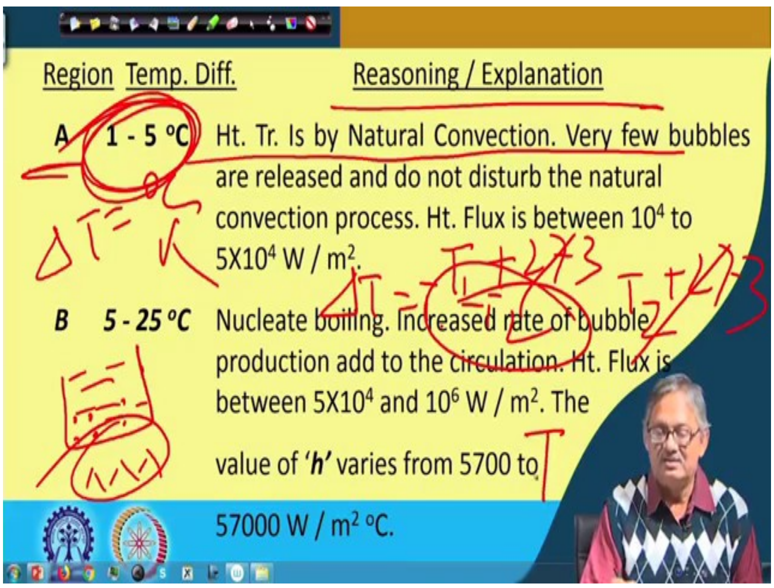

So, where if we look at how what the zones A B C and D are said that the zones are like this, zone A where the temperature difference is 1 to 5 we that is why it was a little shaped, 'right' between 1 to 5 and the residing for this 1 to 5 is heat transfer is by natural convection, 'right'.

So, again we give that example we have this container with water and you are heating. So, in the beginning what is happening few droplet us there coming, 'right'. So, that time it is zone A and the difference between the; difference between that wall and the and the boiling point is between 1 to 5 °C.

Now, ΔT is same in centigrade and in Kelvin, 'right' ΔT is same in centigrade and in Kelvin that you know, 'right' because in centigrade T_1 whatever it be that you make plus 273 and T_2 that also you make plus 273. So, when you are making ΔT that is $T_1 - T_2$ and both these 273 goes out. So, that is why that tells the value, 'right' T the value of ΔT that is T is same in both °C and Kelvin, 'right'.

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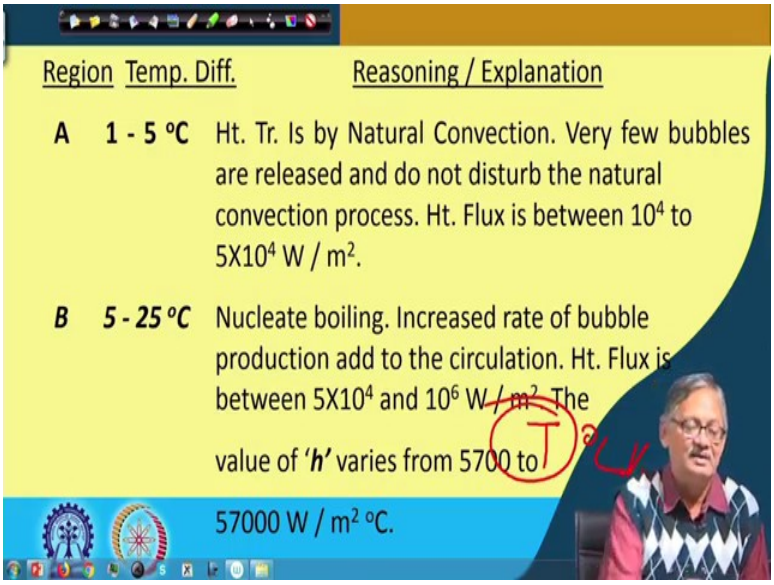

So, if that be true the heat transfer by natural convection is occurring in that, 'right' because here this boils are coming. So, by burn see the hot fluid is going up and cold fluid is going down. So, there is a convictive current and that is called pre boiling or pre convection or natural convection, 'right' very few bubbles are released and do not disturb the natural convection process.

Now, do not disturb the natural convection process meaning that one bubble has formed here, it is going up and in this process there is no reverse direction of the cold fluid that is coming down, 'right'. So, this is how you are not disturbing the natural convection process heat flux is between 10^4 to 5×10^4 that is 1×10^4 to 5×10^4 W/m^2. So, that is the heat flux.

Next zone we have seen was zone B 'right' and in zone B the temperature difference is somewhere 5 to 25 either degree centigrade or Kelvin, 'right' zone B the temperature difference is somewhat 5 to 25 °C and the temperature could be in degree centigrade or in Kelvin, 'right'.

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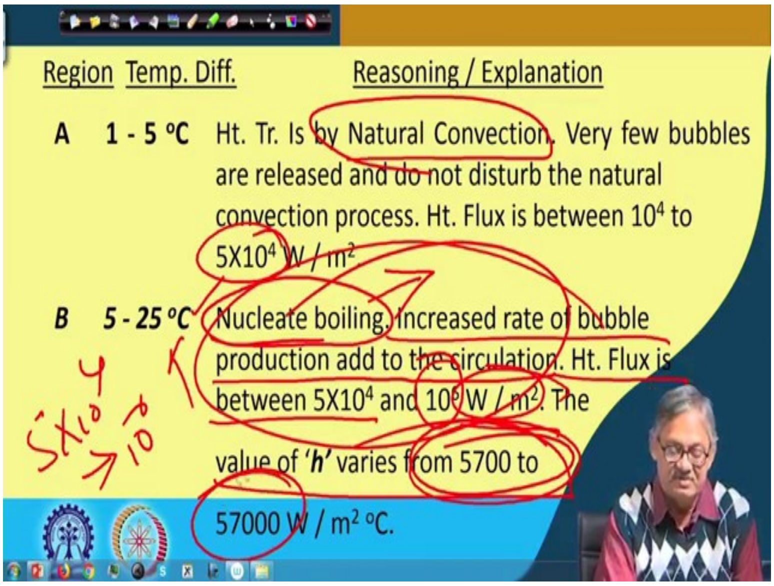

In this what is happening this is called nucleate boiling, 'right'. This is called that was natural convection first then this is called nuclear boiling. So, these increased rates of bubble production add to the circulation. Heat flux is between 5×10^4 after this and 10^6 W/m^2. So, $5 \times 10^{4\text{ to}}$ 10^6 within this the heat flux is there W/m^2, 'right'.

The value of h also varies between 5,700 to 57,000 W/m^{2}°C so, high value of h that is 5,700 to 57,000 W/m^{2}°C that is h that is the heat transfer co-efficient. So, what is happening again that in this water which we add you were giving some heat, 'right' and in the pre boiling pre convection some were there.

Now a lot many after sometime when you will see that lot many bubbles are being formed and these bubbles are going and there is a virtually a convection as well as by means not free, but a little forced that liquid because of the boils see is going up and down that is happening frequently and the heat transfer flux or flux is to the tuned of 5 × $10^{4\text{ to }}$ 10^6 with a high heat transfer co-efficient of 5,700 to 57,000 W/m^2°C, 'right'.

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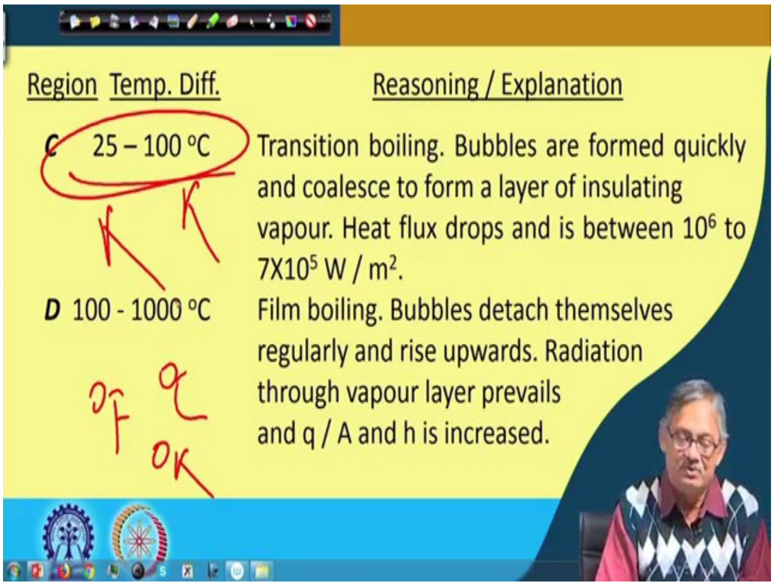

Then we come to the other zone that is C that zone C that where the temperature difference is between 25 to 100 °C or 25 to 100 K. When it degree centigrade it is said degree Fahrenheit it is also said, but it is never degree Kelvin, it is only Kelvin no degree is put there. 'right'.

So, 25 to 100 °C or 25 to 100 K no degree, 'right', ok. Here what is happening transit this is called transition boiling that is zone C. If you remember we had gone this way came back this way went like this and this was zone C, 'right' this was our zone C where this is called transition boiling, 'right'.

Bubbles are formed quickly and coalesce to form a layer of insulating vapour. So, what is happening actually? So, we had again this container and we are heating, 'right' and this was our water, 'right' and what is happening when you were heating like this. So, this liquid droplets are formed, 'right' continuously on this and it appears that this bubbles coalesce, 'right' means they one with other the for they like I do not know whether you are reversing or not that the thermometer which you use that contains mercury, 'right'.

And, by chance if you had this experience ever you should not, but if it got broken, 'right' and that mercury is on the floor or somewhere and they split. Now the moment you bring those mercury droplet us close to each other you will see if the droplet is here and where close to each other. So, they will pull or they will have a force by which they equalize or for from this molar to a bigger one. This is called coalesce, 'right'.

So, the same thing is happening here also that this bubbles they are coalescing and forming a film layer, 'right' forming a film layer. So, bubbles are formed quickly and coalesce to form a layer of insulating vapour. Now the thing is that these bubbles already are formed and they are made some little vapour and this vapour now you are heating and rest of the liquid is here.

So, they are not getting this heat directly because these bubbles are not then going, 'right' they are coalescing, they are forming this film, 'right' and this film in turn is acting as a as insulating material for the heat to be transferred, 'right'. That is why this if you remember there was this depression, 'right'.

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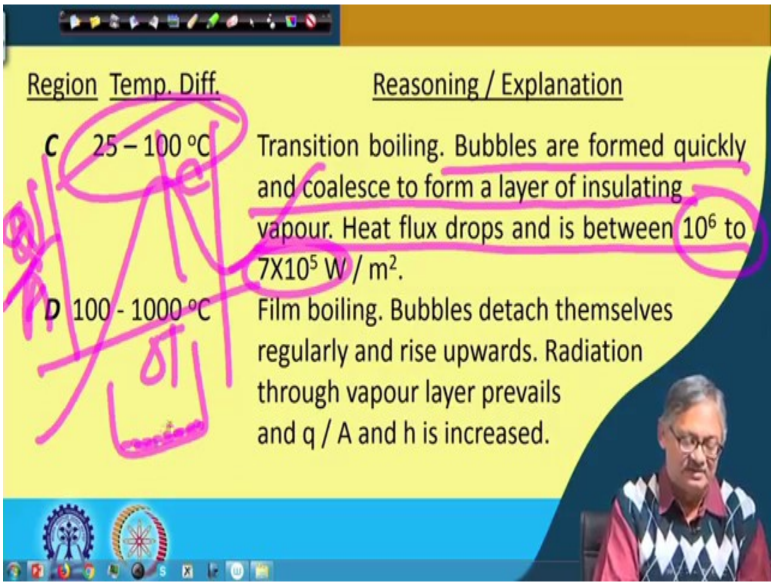

This depression was only because of that, 'right' and that layer is being formed here and we are getting this, 'right'. So, bubbles are formed quickly and coalesce to form a layer of insulating vapour and heat flux drops and is between 10^6 to 7×10^5 W/m^2 that is again and again this is the nature, 'right'. So, from here it dropped 'right' this is the zone C, 'right'. So, it drop this was our q / A or small q / A 'right' and or q / A and this was our ΔT, 'right'.

So, we say that the temperature difference is somewhat 25 to 100 °C, bubbles are formed the coalesce and they act as an insulating material. The vapours are formed they act as an insulating material like this, 'right'.

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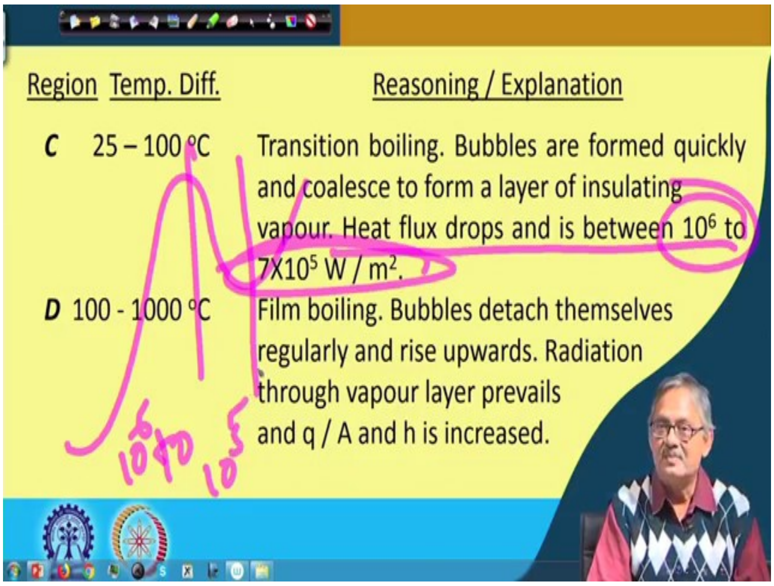

So, heat flux that drops and is between 10^6 to 7×10^5 W/m^2 'right'. So, that dropped like this, 'right'. So, this is from 10^6 to 7×10^5, 'right'. So, this decreases because of that it is forming and that is called transition boiling it is forming a layer of vapour which is acting as the insulating material or insulation against the heat to be transferred, 'right'.

Then that D which was again like this and this 'right'. So, this zone we said again it is increasing, 'right' this zone again it is increasing and this is called film boiling, 'right'.

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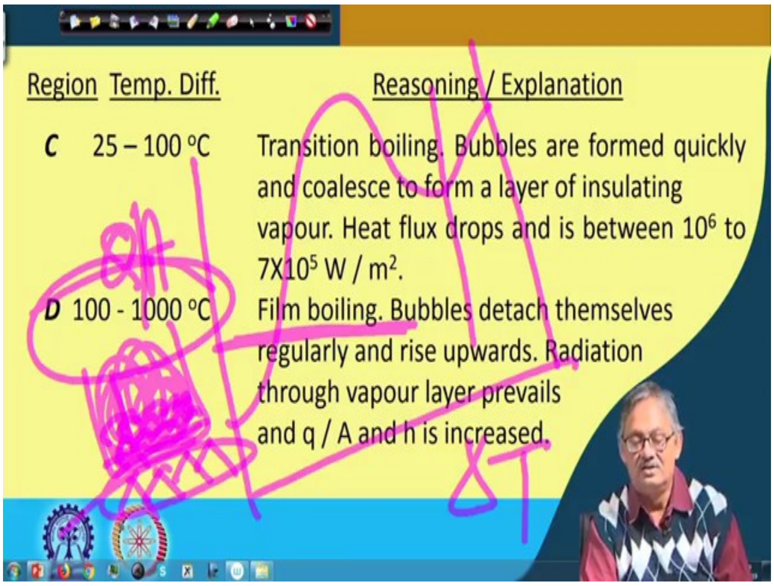

So, the film was produced here and now because they are this heat transfer has become 5 that is your q/A q/A that has gone very high like this, 'right' and this is increasing ΔT also got increased. So, this is between 100 to 1,000. So, lot of heat is being supplied and this layers which were formed now they are so quickly disappearing and there is a real dancing of the bubble and this is mixing and that is how this is called film boiling, 'right'.

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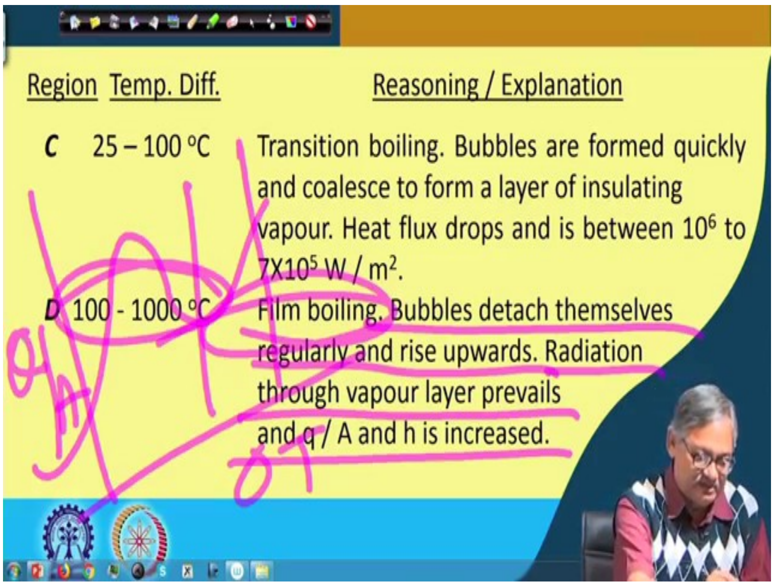

This is called film boiling bubbles detach themselves regularly and rise upwards radiation through the vapour layer prevails and q/A and h both increased, 'right'. So, again this has gone up so, q/A. So, this has increased and ΔT is also very high to the tune of 100 to 1,000, 'right'.

So, if we look into the total system that what is happening during bubbling. I tried my best to convince you or to give you example through the daily what you come across experience, 'right' that making tea like that, 'right' if you watch then you can easily make this difference, 'right'.

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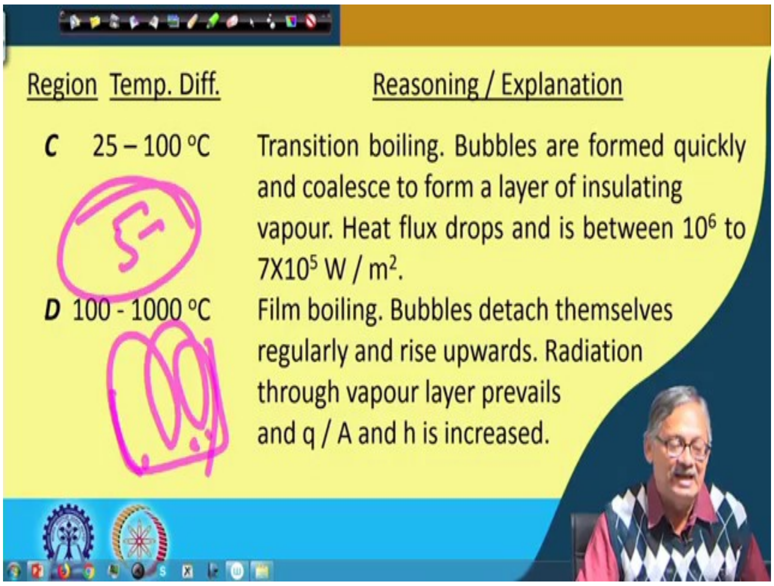

So, initially when you have given for making tea to water to boil initially the droplet us were formed very low, 'right' like that few droplet us were formed and the ΔT there is between 1 to 5 or 5 to 10 within this range, 'right'. And, we said there that q/A was also very low few drops are formed and there is a natural convection which is happening in that, 'right' and we had said that this zone that was zone A and this zone we said to be nothing, but due to natural convection, 'right'.

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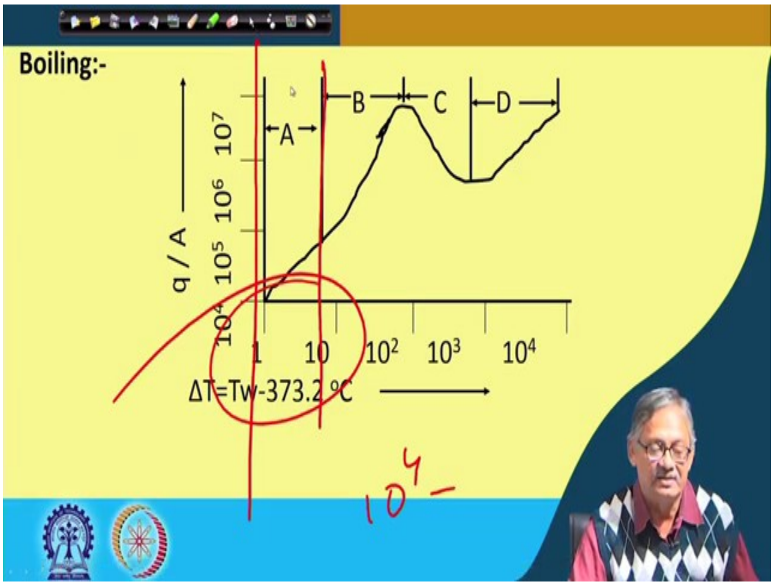

I put this again before. So, this is called natural convection, 'right' and this is how it was and the ΔT is between 1 to 5 or a little more, 'right' and natural convection q is also very low it was set between somewhere 10^4 in 10 to the power somewhere 5 if we are correct, 'right'. It was 10^4 to 5×10^4 'right' ΔT was 1 to 5, 'right'.

So, if there be true then we can say that we can say that 5×10^4 this much W/m^2 was the heat 10^4 to 5×10^4, 'right'. So, this picture you keep in mind all the time we are not able to go and I mean go back and come back. So, to and fro is difficult here. So, these picture if you remember that they are making like this like that and this, 'right' out of which we have made 4 zones and one we call A second we call B third we call C and fourth we call D all these 4 we had given the example of making T that which you are heating with water in some container, 'right'.

This example we have given. So, and there are 4 different distinct steps for boiling and they are A that is natural boiling or natural heat transfer, 'right' natural convection heat transfer very few bubbles are formed then B that is within 5 to 25 this is called nucleate boiling where the rate of bubbles formation are increased heat transfer also heat transfer co-efficient also goes very high around 5,700 to 57,000 and the flux is around 5×10^4 to 5×10^6 then suddenly it drops.

Because, these bubbles coalesce and forms a layer, 'right' and that layer the vapour layers acts as the insulating material or insulation. And, the heat transfer is reduced and it comes down from 10^6 to 10 to 10^5 or 7×10^5 precisely it is reduced and the and the flux reduced to that level and this is called transition boiling

So, after transition boiling again the this bubbles which you have formed which coalesces now they breaks and moves very fast and that is what we said that dancing of the bubbles in the liquid and that is happening and lot of heat transfer take place and q by A that is flux that goes up from that 10^5 which was down to now gradually again up, ‘right’. So, this is the boiling heat transfer mechanism, ‘right’. So, with this since our time is over I do not say the time is I mean time is still there it is over we have extended, but still you look at and see the food zones of the bubble heat transfer or boiling heat transfer.

So, next we will go into the more some more detail or mechanism or heat transfer equations.

Thank you.