Heat Transfer
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Lecture - 39
Boiling I

So, we are going to start a new topic today.

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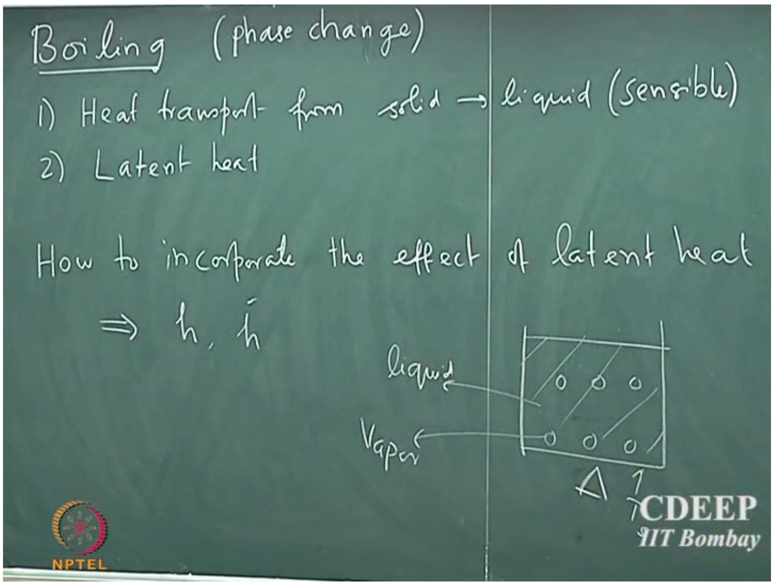

When I look at boiling, so, the so far all the process is heat transport process if we looked at we assume that the heat transfer occurring from let us say solid to a single phase or from a single phase fluid to a solid. So, what we going to see is in boiling what happens that the there is a phase changes is involved. So, there is a phase change is involved in boiling process and in fact, the same thing is involved in condensation if you will next topic if we will look at; so in boiling in addition to. So, heat transport from let us say solid to liquid will also have latent heat. So, it is not just the sensible heat that controls the heat transport process that also the latent heat of the fluid controls the net amount of heat that is transported.

So, what we are going to see is how to incorporate latent heat in the heat transport calculations, and to retain our original objective is the objective is to find the heat transport coefficient h and h 1. So, those are the objectives. Now suppose if we have a fluid and this is something that all of us have en counted some point like boiling water we have always done that. So, if you take a beaker take any container. So, I am going to supply heat, I am going to heat the bottom of the container, and have fluid which is sitting here ok.

So, the question we want to ask is what is the net amount of heat that is transported from the solid to the fluid? Now it is not just enough to say solid to fluid we have to qualify it with something else and the reason is that the fluid is now boiling and there is change in the phase of the fluid. So, the fluid is now going from. So, this is the vapor state of the fluid, and this is the liquid state of the fluid. So, therefore, the net amount of heat that is transported, it depends upon what fraction of this fluid is going to be in the vapor state. So, therefore, we will have to now incorporate the extent of vapor which is formed inside this beaker in our heat transport calculation. So, it is not enough to simply know what is the amount of latent heat, but it is also important to what fraction of the fluid was converted to the vapor state.

Because there is latent heat which is involved here and so, whatever heat that is supplied from the surface of this container the bottom surface of this container, let us say that I know I can maintain this let us say at some surface temperature T s. So, I heat giving supplying heat and whatever energy that is supplied to the surface is now taken up by the fluid, and the fluid sensible heat is going to increase and moment it reaches the boiling point or the saturation temperature at the given conditions, some fraction of this fluid is going to get converted into vapor phase.

Now, it is continue to further heat will be more fluid, which is going to become vapor and that is what we have observed when we actually heat water in our kitchen fine.

All of you must have seen this either you have done it in yourself or at least you have observed this. Where when you heat something you will always see that a different time points although you can still maintain at a same temperature and you can maintain constant you can you can provide heat at a certain flux, you will see that the amount of vapor which is being formed is actually varying all right as you supply heat to this container. So, what we are going to see in today’s lectures is, we are going a see how we can attempt to find heat transport coefficient, based on what are the different types of boiling. There are based on the fraction of the fluid which is converted into vapor phase you can classify the boiling process into four different types. So, we are going to first describe; what are these different types of boiling stages? And we are going to see how to capture the heat transport coefficient for each of this phase.

So, in order to do that, we need to first look at how to perform a controlled experiment. The controlled experiment was performed and the way controlled experiment was performed is instead of heating from the bottom of the container, platinum wire is placed inside at a specific location.

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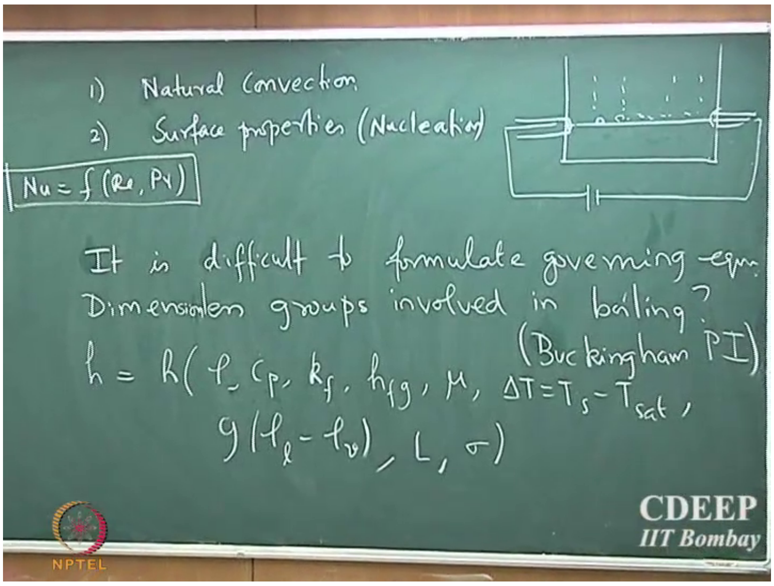

The straightly above the bottom surface, then you provides. So, electrically heat is the platinum wire and so, you will start seeing vapors which is formed. Now because the vapor is lighter they are going to travel through this liquid, and they will start moving towards the upward side and the liquid is going to displaced right. So, therefore, clearly one can see that, there is a natural convection process which is involved clearly natural convection is involved. Here because the fluid particles which are actually flowing into vapor stage is.

Now, going to be lighter also they have to be displaced also that is sets up a natural convection motion. Now the second thing is it is; obviously, going to be a function of the surface properties, particularly the nucleation process. So, let us see little more details about this in a short while so, the bubbles which are actually nucleated on the surface where the heat is being provided to the fluid. So, you will see that the nucleation is the strong function of the properties of the surface. So, if t he if the surface is very rough then certain locations are preferred for nucleation over other location in the same circles. So, the surface properties and other properties say play a strong role in boiling process ok.

So, before we go into the details, one of the important things was that the it is almost impossible it is very difficult to formulate governing equations. Now it is not impossible to do that the only reason that you are not introduced to two phase flow, remember that it is a two phase system. So, if you know how to characterize two phase system which is beyond the scope of this class, we should be able to write governing equations. That let us assume for now that it is not very easy to do that even the background of the scores. So, one way to look at is, but still we can get some iterative idea as to what is going to happen. So, the way it looks at is. So, suppose we want to perform or we want to find what are all these dimension less quantities, which are involved here ok.

So, what are all these dimension less groups involved in boiling process? Because all the convection topic that you have seen were always found that there is a relationship between the Nusselt number and the dimension less quantities, which is actually characterizing the transport process, whether it is heat transport or mass transport or momentum transport right.

So, therefore, if we know the dimension less groups, then we can get some clue as to how to find the heat transport coefficients. So, what is. So, what we are going to use we are going to use the dimension analysis, going to use the Buckingham pi theorem, which has been talked in your field mechanics class.

So, the heat transport coefficient will be a function of what are the different properties or aspects of this problem, which is going to decide the heat transport coefficient yeah. What are the different quantities or properties of the fluid, which is going to influence the heat transport coefficient? So, remember that all the dimension less number we got, they are combination of some properties of the fluid right.

So, the objective is to find out what are these dimensions less groups. So, you need to know what are the properties of the fluid on which the heat transport coefficient is depend upon depends upon right that is what that is the objectives fine. So, remember that you always found for a general system you always found Nusselt number is some function of re and Prandtl number all right. So, this is what we found for all the systems we have looked at so, far.

And Reynolds number capture uses the properties of a fluid and captures the momentum boundary layer because here and Prandtl number captures the thermal boundary layer behavior based on the properties of the fluid. So, similarly; so from here you can clearly see that heat transport coefficient it is a function of some combination of the property. So, if you can identify what this properties are, on which the heat transport coefficient is going to depend upon, he could actually do a dimension less analysis and find out what is the dimension less group by using the Buckingham pi.

So, what are the properties density? So, that is yea C p density the capacity which tells you what is the sensible heat that the fluid is going to take, conductivity kf yeah latent heat. So, hfg is the latent heat of vaporization of the fluid. So, we got 4.

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Viscosity right because of natural convection, then.

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Yeah temperature, what temperature?

Student: (Refer Time: 13:10).

Is it surface temperature? So, remember that we are looking at the amount of heat that is transported. So, that depends upon.

Student: (Refer Time: 13:22).

No depends upon the temperature difference, which is the difference between the surface and the saturation temperature that is the boiling point of the fluid then what else?

Student: (Refer Time: 13:38).

Yeah.

Student: (Refer Time: 13:44).

Yeah, but particularly when we are looking at boiling, assume that the fluid is actually at the saturation. So, that is yeah what else? So, natural convection. So, we said viscosity, but what else gravity right somehow the buoyancy has to play a role here right. So, it will be g times rho liquid minus rho vapor. So, that tells you what is the force body force difference between different locations in the fluid, and that exhibits the bias and from here then 1, 2, 3, 4, 5, 6 7 what else? That is it now this is depends upon length of the wire right you need to know what is the length of the wire anything else yeah?

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Because the amount of the area that is available depends upon the length. So, the length scale tells you what is the area that is available for heat transport? So, it has to be a function of the length. Remember Nusselt number you have h into l by k or d by k if it is the if it is a prolong coordinated system what else? So, we have got viscosity, we have got sensible heat we have got rho, another important aspect I will give you a hint. Suppose if the vapor is the now forming at the surface of the wire that is already checked in workout because buoyancy tells you the difference in the density that is good enough. Now suppose if you have a vapor bubble, which is formed at the surface of the wire.

Now, the extent of heat that is carried by the vapor depends upon what factor? C p of the vapor, but something more than that, you need to have a contact right. So, you are looking at heat transport from the wire to the fluid. So, it is a strong function of the surface tension. So, if the surface tension plays a very strong role in actually defining what should be the extent of contact, whether of this fluid with the wire.

So, you have 10 different factors which are actually play a role in defining, what is the heat transport coefficient all right. So, I would not go into the details of Buckingham pi because that is been covered in your fluid mechanics class. So, if you use the Buckingham pi theorem so, you will get 5 dimensions less groups.

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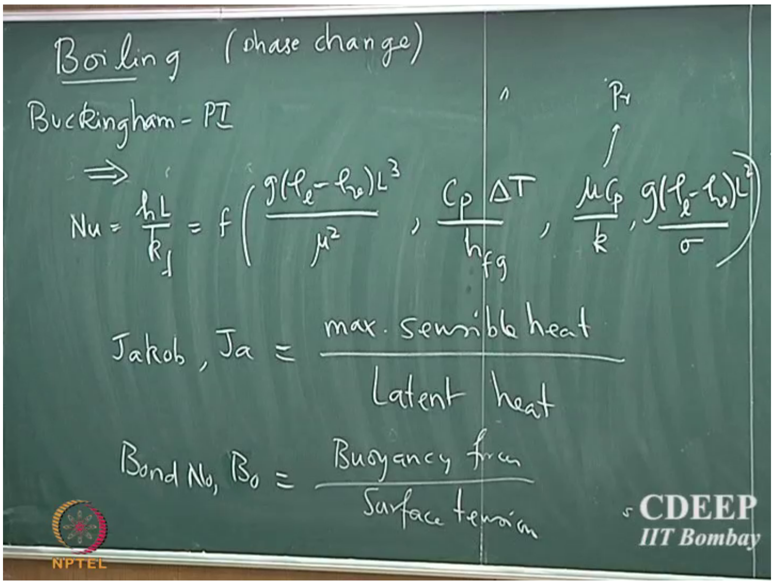

So, that will be Nusselt number equals to hL by kf and there will be a function of g rho l rho v, L cube by mu square comma C p delta T by and mu C p by k which is Prandtl number l square by sigma what is C p delta d by hfg? Hfg is the latent heat. So, that tells you.

So, this is called the Jacob number that is the ratio of maximum sensible heat divided by latent heat. So, the ratio of the sensible heat that is carried divided by the corresponding latent heat. So, this tells you what is the fraction of the heat that is supplied to the fluid particle is carried as sensible heat and what fraction is actually used for phase change. So, whatever heat that is supplied to the fluid is what is being used for transport of heat we have sensible heat and also for change in the phase. So, the last one is called the bond number. So, that Bo this is Prandtl number known as, bond number is ratio of buoyancy forces to surface tension forces. So, that is the bond number now.

So, these are the 5 dimensions less group that will come out of the Buckingham pi theorem. I think all of you should actually try to get the five groups, we go back to your fluid the canings notes where Rubin part what how to derive these dimension less groups and find out what these 5 dimension less groups are from starting from the fact that the heat transport coefficient depends upon these line factors here ok.

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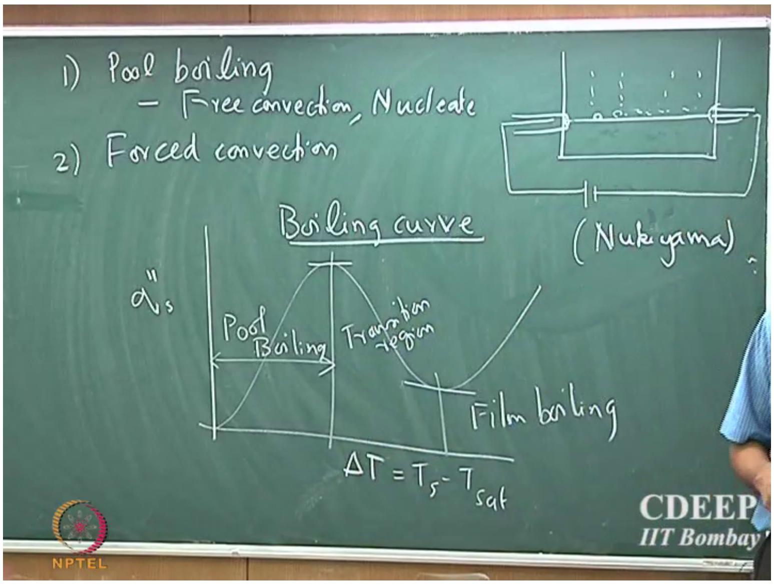

So, that two classes of boiling, one is called the pool boiling and the other one is called the forced convection boiling. So, it might be a bit surprising to see forced convection here. So, we will see that although the fluid is not being pumped or it is not being forcefully made to flow towards something, that you will see that there is a certain type of forced convection which is involved and we are actually discussed very deeply when we go to that topic ok.

So, in pool boiling there are two type one is called the free convection mode the other one is called the nucleate boil nucleate pool boil. So, what was observed this experiment was done by person name Nukiyama. So, what he have observed is that, because it is a very controlled experiment you can find out what is the net flux of heat that was actually or net flux of energy that was transported to the fluid. So, you made a plot between qs and delta T. Now here we assume that when you start the experiment the fluid is almost at the saturation temperature ok.

So, this is T s minus T sat. So, not that saturation temperature is fixed in a given fluid, I under given conditions the saturation temperature or the boiling temperature is fixed. So, what he observed is something like this. So, we are going to explain in a short while, I am going to explain what the why you get such a curve and what is the significance of this. So, suppose I. So, so this is the kind of curve that he obtained, and what was observed is that there is a maximal heat flux on the curve and there is a minimal heat flux in that way.

So, this is what is called as a boiling curve, and the location up to which the maxima arises maxima of gs this region before that is called the pool boiling region called the pool boiling region and this region is called the transition region called the transition region and this place is called the film boiling region. So, these are the three different stages of boiling.