Heat Transfer
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Lecture - 36
Introduction to Free/ Natural Convection

You remember one of the classes I mention this coffee cup, example where I just place a coffee cup here and then which is let us say, that 50-degree 60-degree whatever temperature and then you leave it out leave it there isolated. So, it is going to reach equilibrium with the surrounding temperature let us say 25 degrees. So now, one would guess that; obviously, there is convection mode of heat transport, but what is not; obviously, to see is that also connective mode of heat transport in the same process. So, note that in this example there is no pressure driven flow, it is just fluid which is sitting in a coffee cup right?

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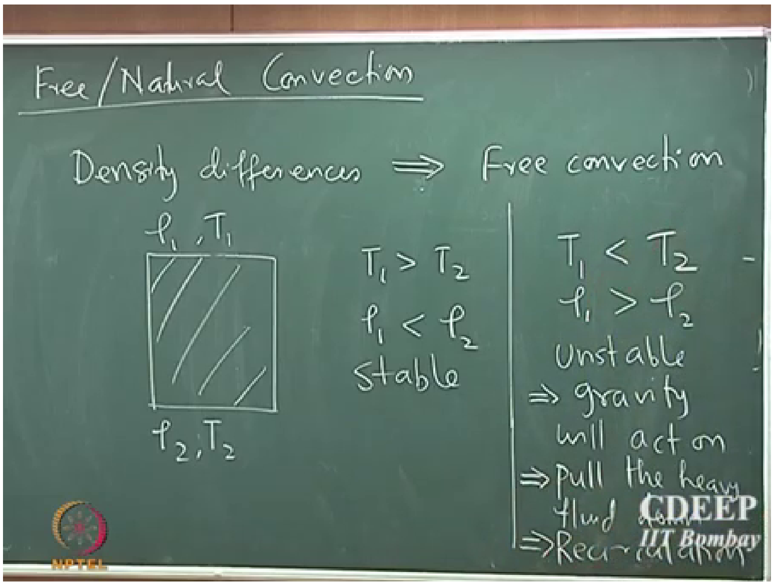

So, what happens is that the density differences that will result, because of change in the local temperature, we going to lead to what are called free convection flows. Now, an easy way to see that is suppose I have a box, which is filled with the fluid very similar to your coffee cup example, except that I now close the top and I will make sure that the fluid is filled all the way to the top of the enclosure. So now, if I maintain let us say that I maintain the temperature of the top surface is T 1 and the bottom surface is that T 2, now if T 1 is greater than T 2 what can we say about the density, density is a function of temperature right?

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So, what can you say about the density temperature is higher density will be lower right? Because when the temperature is higher you allow the fluid to expand. And so, we expect that the density of the fluid at the top surface is going to be lower, than the density over fluid at the bottom surface. So, that is a very stable situation where light fluid is now sitting on top of the heavy fluid. So, that is a very stable situation, now if I take a parallel where I put T 1 is less than T 2. So, let us say I am able to maintain the temperature above which is lower than that of the temperature below and. In fact, this is what happens when you leave the coffee cup idle on a table.

So, the bottom of the table temperature would quickly equilibrate with that of the coffee and the top is now, exposed to the atmosphere is that a lower temperature. So, you expect that the density of the fluid near the top surface is going to be greater than the, density will get leads to the bottom surface. So, that is an unstable situation where you have a heavy fluid which is now sitting on top of the light fluid. So, what will gravity do? It immediately pull the heavy fluid to the, to flow below and light fluid will move up. So, gravity will act on it now and it will pull the heavy fluid down. And so, what it result is a circulation of the fluid. So, this result in a recirculation.

So, this results in a recirculation of the fluid although it is in the same enclosure, you are not adding extra fluid from outside there is no post convection the fluid is not forced to go there is no pressure during flow it simply, because of the temperature difference it results in the density difference. And so, gravity will now start playing a role and there will be recirculation of the fluid, the moment there is recirculation you start having convection current right? So, whenever there is flow you have convective mode of heat transport. So, what we going to see is, how to characterize the convective mode when you have free convection.

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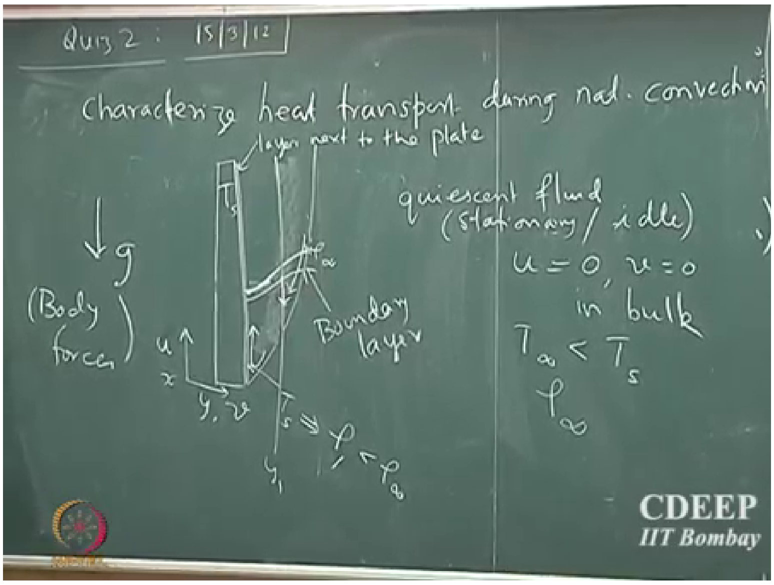

So, what we going to see is characterize heat transport during natural convection. So, that is what we going to see. So, the first example, we gone a look at is suppose if we have a plate, let say a vertical plate which is let us say at maintain at a temperature Ts and there is lot of fluid which is present and suddenly, I am putting this vertical plate to the fluid. So, there is a fluid which is now stationery it is not moving, but I am suddenly putting this into the fluid now this is not a bad example, lot of quenching process industry actually done this way, where a hot material is suddenly dump into water.

So, suppose I have quiescent fluid which is sitting around, quiescent means basically stationary or sitting idle the fluid which is just sitting idle, it is not moving it is not doing anything and therefore, the bulk velocity is 0 in all directions. So, if I give coordinate now if this is my x direction and u is my x component velocity and this is y direction, v is my y component velocity then both u and v are 0 in bulk.

But then what happens to the fluid which is close the plate because the fluid. So, let us say that this is a temperature T infinity, which is smaller than the temperature of the plate and that exactly what do you do, when you have a quenching exercise where the you want to reduce the temperature of the material. And so, you quickly double the water. So now, if supposing the bulk temperature is smaller than that of the plate temperature, then very close to this plate the fluid which is present is now going to have a density gradient, and that leads to what is called the boundary layer and explain in a minute why this boundary layer is formed. So, suppose I take the I look at the fluid particles, which is close to very close to the surface.

So, they will quickly equilibrate and they will reach the suppose this is the layer, very close to next to the plate that is a layer next to the plate. So, they will quickly attempt to equilibrate and reach the temperature of the surface. So, which means that. So, supposing if the density of the fluid in bulk is rho infinity, then what will be the density of the fluid here it will be greater or lesser, it will be lesser because we said Ts the surface temperature is larger than the fluid temperature right? So, the. So, if I call it rho one this will be lesser than the bulk density. So now, if I look at sorry supposing I go further down into the plate, now this the fluid which is present in this location is exposed to the surface of the plate for a much larger period, than the fluid which is present here right? So, I am just dumping it inside. So, this fluid particle which is present in this location will now have a density gradient.

So, suppose I say that rho 1. So now, it will have a density gradient, it slowly reach the density of the bulk. So, this density of the fluid here this was the density profile, density of the fluid here will be lesser than the density of the fluid will be bulk review. So, therefore, close to the surface you establish a density gradient in the vertical direction and so, the fluid which is present here.

So, this is a bulk fluid. So, the bulk fluid is start flowing down, the fluid which is present close to the boundary layer is will start flowing down and the fluid which is present here, will start moving up. So, this sets up a recirculation and this leads to a convective mode of heat transport, very close to the surface not far from the surface and these boundary layer thickness is, typically much smaller than the boundary layer thickness that you would get in a post convection period.

So, therefore, what we are going to see how to write the equations for this kind of a problem and how to find heat transport coefficient for this kind of a problem. So, suppose I take a density profile here, now I look at the density profile in this location here while look at any plane here, any plane at any y let us say y 1. So, this density profile is going to cost a density gradient in y direction and therefore, it going to move down.

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It is going to move up here. So, one thing.

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Yeah, why should y?

Student: (Refer Time: 11:44).

Right?

Student: (Refer Time: 11:50).

Correct no, no see, when I say it is rho 1 it will try to quickly equilibrate, but then as soon as you drop that plate inside not every location is going to equilibrate (Refer Time: 12:02). So, as soon as you drop the plate itself you will start seeing recirculation of the fluid, but this aspect of it reaching the same temperature in the same density, is after the plate is exposed to a sufficient time inside the fluid. So, the recirculation will start as soon as you drop the plate inside. So, that is the transient. So, the transient itself is set of the motion for convection in the boundary layer and that will continue as soon as the plate is still placed inside after the plate is replaced there.

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Y direction yeah this is gravity in this direction.

Student: (Refer Time: 12:36).

Correct.

Student: (Refer Time: 12:47).

Fine.

Student: (Refer Time: 12:51).

Yea, but you have to be very careful that here the motion is going to be 2 dimensional, see I gave a one-dimensional example just to get an insight, but really the motion is going to be 2 dimensional. So, even though gravity is acting in section below the (Refer

Time: 13:06) be a component, which is actually make the fluid to move on the other side. So, it is a 2-dimensional motion you will have both u and v inside the boundary layer.

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Rho at where.

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Yeah.

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Yeah that is correct.

Student: (Refer Time: 13:34).

Right, but that is if I look at 1 plane, but boundary layer is not a plane, boundary layer is not a single plane, right? So, is the boundary layer opposing is a boundary layer and also to be a single plane, then you would expect that nothing is going to move, but the extent to which the fluid is peeling the presence of the plate is not the same at every location along the plate. If you (Refer Time: 02:25) be same at every location along the plate then what do you say right, where it is not the same.

So, therefore, we are going to set up a 2-dimensional motion and that is a reason why you have a certain shape. So, anyway, what we going to see now how to characterize this equation, so far, we always ignore the effect of gravity and in fact, we ignore the effect what is called the body forces. So, what we are going to see in todays in the next lecture is, how to include the body forces and characterize the heat transport process.

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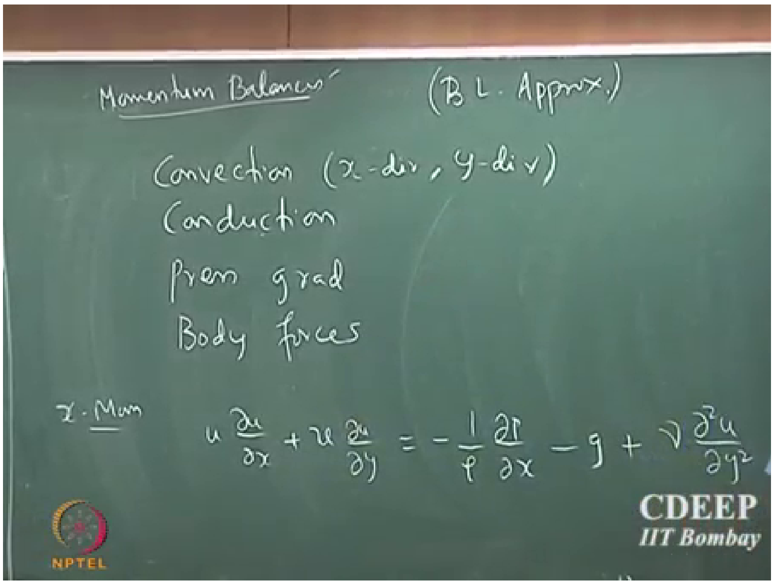

So, we have to write the momentum balance. So, in order to characterize the process is we need to write the corresponding balances. So, let us write the x momentum balance. So, what is the x momentum balance? So, let us say what are the process is which are involved remember that 2 ways of writing, you can start from first principles from shell balances or you can identify, what are the different process is and you can you know what is the mathematical representation of each of these process is, and you put the correct sign and join them.

So, what are the process is? So, we have convection in both x and y direction x direction and y direction, we have conduction process then, we have pressure gradient even, we have body forces. So, these are the 4 terms which are involved also we can easily write the x momentum balance, udu by dx plus v du by dy that is equals to minus 1 by rho dt by dx minus g plus mu into d square u by dy square. Now, this is after assuming boundary layer approximation and including the boundary layer approximation. So, this is the x momentum balance and the y momentum balance is the equation dt, dt by dy that is 0. So, that will be the y momentum balance, when you introduce the boundary layer approximation.

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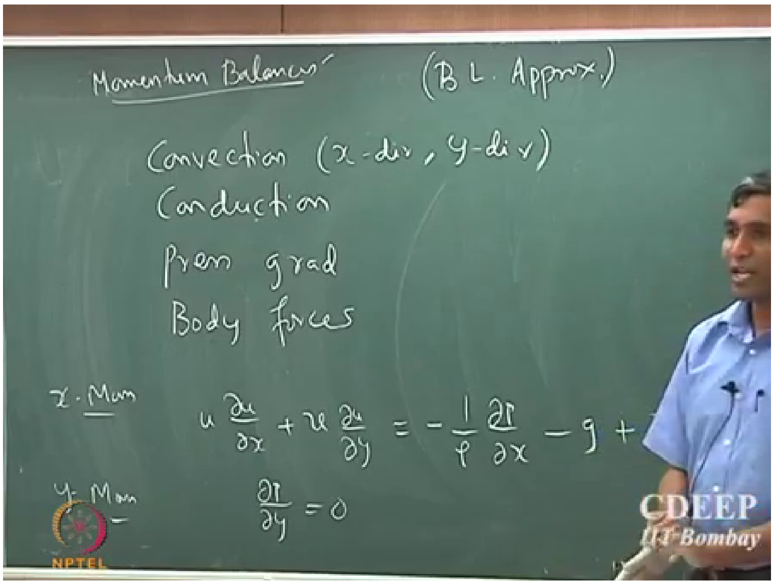

So, what you will do in the next lecture is how to take these momentum balance and the energy balance, that we are going to write how to non dimensionalize? Remember that when you non dimensionalise for all the cases, we did so far there was always a reference temperature and reference velocity. We always had a free steam velocity and free steam temperature, unfortunately there is no free steam velocity here, we have a free steam temperature which is t infinity, but there is no free steam velocity.

So, we are going to see now in the next lecture as to how to handle this kind of a situation, where there is really no reference velocity, still how to non dimensionalise this and to characterize the processes and what kind of non-dimensional quantities that we will get.