Conduction and Convection Heat Transfer

Prof. S. K. Som
Department of Mechanical Engineering
Indian Institute of Technology – Kharagpur

Lecture - 02
Introduction and Fundamental Concepts II

Good morning and welcome you all to this session of the course conduction and convection heat transfer. Last class we were discussing the Fourier laws of heat conduction, which defines the heat flux is proportional to the temperature gradient and the proportionality constant is called as or defined as thermal conductivity, which is a property of this system.

Now in this regard again I repeat that the two modes of heat transfer conduction and convection is this way that conduction is the basic mode of heat transfer and when there is a flow in a medium, which is present in liquids and gases, then this conduction mode is affected by the flow and we call it as a convection mode. So therefore, convection mode cannot appear in solids, the heat transported in the solid is always by conduction mode purely without being affected by flow because there is no flow within the solids.

Solid as a whole can be translated, but within the solid there is no flow and under some special conditions when the fluid, the liquid or gases are stationary, there is no flow then the heat transfer takes place purely by conduction and when we will talk about conduction heat transfer, we will consider purely conduction mode without being affected by any flow that means there is no flow in the medium, which mostly happens in solids.

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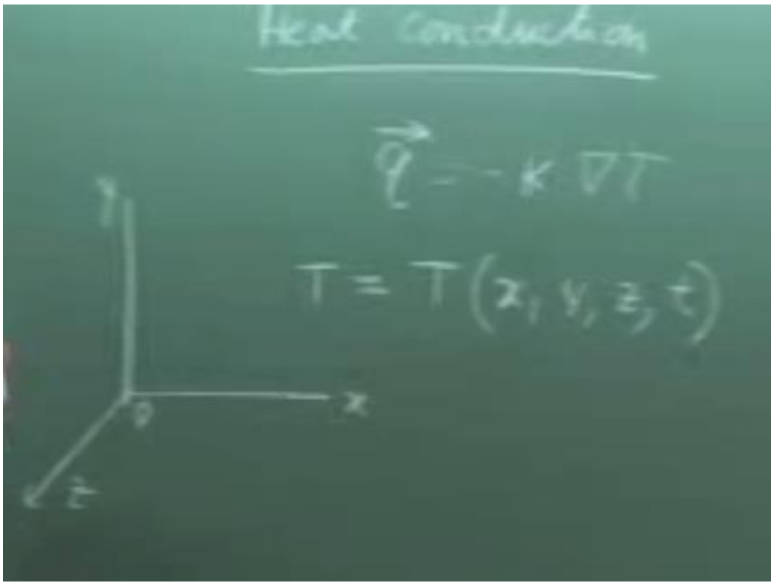

And if we, now think that the heat conduction, heat conduction again then we have seen that the heat flux that is the heat transfer per unit area normal to the direction of heat transfer is minus K gradient of T, where the heat flux is taken as effect. Now therefore, there has to be a temperature variation in this space coordinates. It is a continuous temperature variation for which we can define the gradients that means in the medium.

The temperature has to be a function of space coordinates if you consider a Cartesian coordinate system x, y, z simple that T is mathematically expressed as a function of space coordinates x, y, z and also it can vary with time that means that any point the temperature can also vary with time that means temperature is varying with the space coordinates. So there is a temperature distribution and this distribution is also varying with time that means the function of time.

So, in general, one can express temperature in a medium of heat conduction or in any medium, but here now we are discussing the heat conduction in a medium of heat conduction is a function of x, y, z space coordinate and time.

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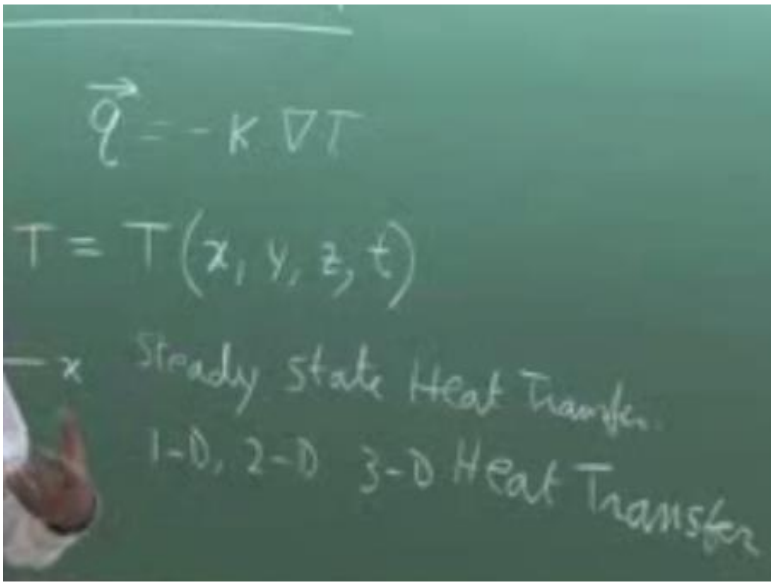

Now in this regard we should think of two states that one is steady state heat transfer and is one dimensional, two dimensional or three-dimensional heat transfer. Now in steady state transfer as you know what steady is associated with invariance with time that means something which does change with time. For example, you know the study flow were the flow velocity pressure, these quantities and the derived quantities like mass flow rate, volume flow rate are all in variant with time.

So, for a system at steady state, do you know the properties are invariant with time except for the control mass system, which is defined as a fixed quantity of specified mass, mass is excluded other properties are invariant with time because mass is always invariant with time, so we do not bring mass same in steady condition mass is constant. But for a control volume system or control volume inclusive of mass everything should be constant with time that means all parameters, all properties will be constant with time.

So therefore, temperature being a parameter, temperature is or a property of a system remains constant with time under steady state situation and we are concerned with the heat transfer processes at the moment.

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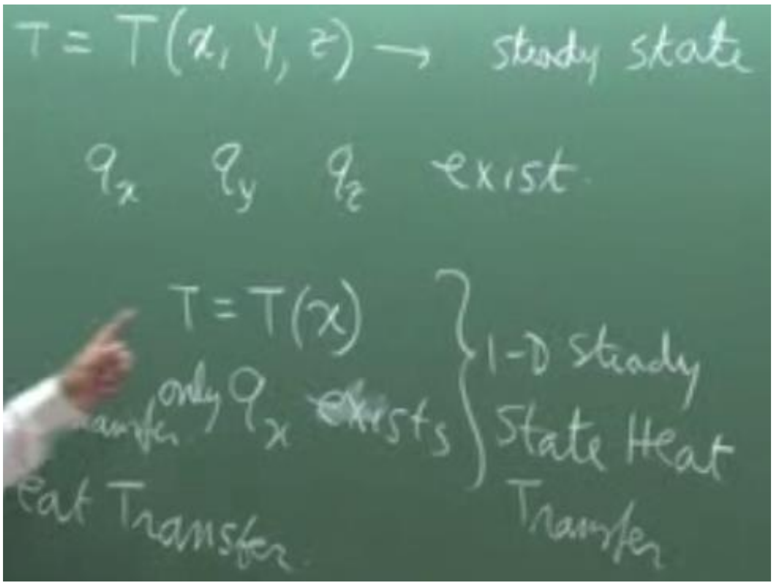

So therefore, when the temperature ceases to be a function of time under all steady state situations, we call it at steady state that means in that case temperature becomes a function of space coordinates that means that at steady state transfer, temperature is a function of space coordinates only that means if we get a temperature distribution within a medium that remains invariant with time. Now when temperature is a function of three space coordinates, the heat flux in all these space coordinates exists.

Because of the respective temperature gradient and these heat transfer situation is known as three dimensional. If this is not a function of time, then it is a steady state heat transfer process. Similarly, if the temperature becomes a function of only two coordinate systems ceases to be a function of z, then it is a two dimensional or any two x, z depending upon the way you define your coordinate axis.

And if the temperature is a function of only one space coordinates that means temperature varies only in one direction, so heat flux exists in that direction only that is a one-dimensional heat transfer that means only qx exists that is one dimensional steady state heat transfer. So, this is the mathematical definition of steady state transfer one dimensional, two dimensional or three-dimensional heat transfer.

Let us concentrate on one dimensional steady state transfer a temperature ceases to be function of time and it is a function of only one space coordinates along which there is a heat flux.

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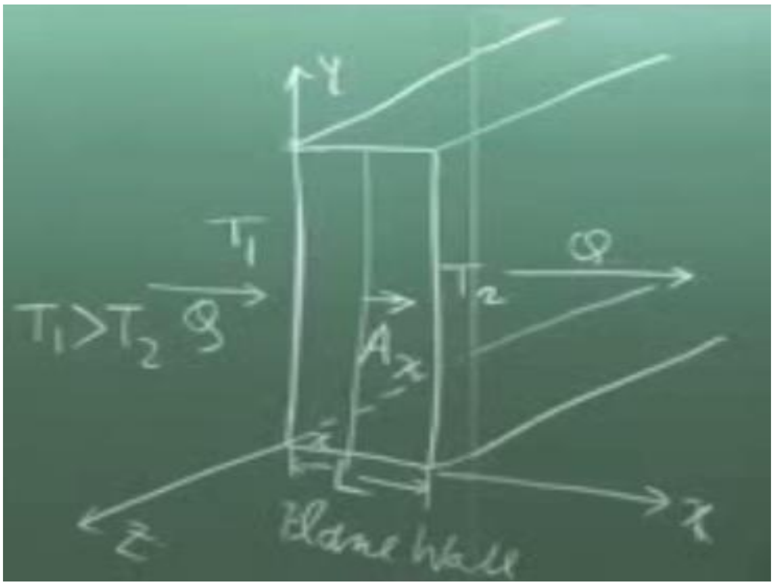

So, to realise this in practise let us consider a wall like this whose dimension in this direction, which we call length or width is much small L compared to this dimension in this and this direction that means if you consider this to be x, this direction to be y and this to be z that means this dimension in y direction, which you can call height its dimension in z direction, which you can call as the breadth or whatever may be is much higher as compared to this width or length L.

If you consider such a situation of a wall or a slab, which has a constant cross-sectional area with respect to the axis x, that means the plane wall of this dimension this is known as plane wall and if we consider a situation that the left-hand surface is kept that a temperature T1 constant, the surface temperature is constant. That means at each and every point on the surface that temperature is T1 that means which is independent of y and z direction.

And if this right-hand surface is kept that a constant temperature T2, this we assume this is the prescription of the problem, that means problem is specified like this T2 and if T1 is greater than T2 by your basic definition of heat transfer, heat will flow in this direction from high temperature to low temperature. Now this case assumes a one-dimensional heat transfer why because temperature varies only in the x direction.

It is by intuition the temperature at any point will be a function of x only because in y and z they are constant. The boundaries are such the boundary conditions have been made such that the problem is made one dimensional because of the boundary condition and the geometry. The temperatures are constant in two phases and moreover this dimension, the length or width, is much smaller compared to the dimensions in other direction.

So, by the definition of the problem by its geometry and boundary condition it is one dimension, now how to conceive of a steady state. Now by basic understanding of the steady state, all points that temperature has to be invariant with time, there may be a distribution but invariant with time, so to meet up that we have to approve physical requirement. One is that definitely the boundary temperatures has to be invariant with time, which I have prescribed for this problem.

And at the same time there should not be any energy generation internally by this wall by any action, there may be an internal reaction or anything else. At the same time, there should not be a heat absorption by any action within the wall and wall should allow the heat to flow without interruptions that means without adding anything to it or without taking anything from it, which means that the heat flows at any section will be constant.

And I can tell the amount of heat, which is coming in to this wall from the left side is going out from the wall at the right side, the same heat.

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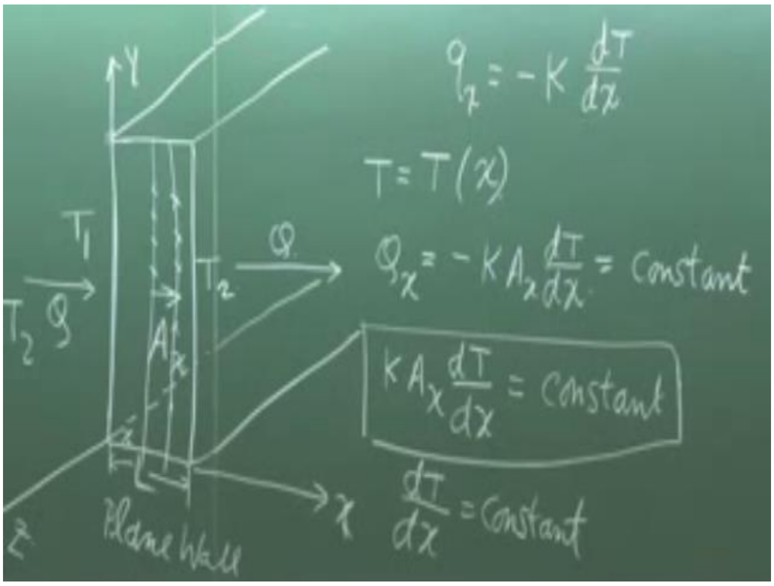

Now if I take a section at x and let the cross-sectional area is Ax, then what is the heat flux qx is minus K dT/dx. Now T is a function of x, so therefore T Tx can be either a function of x or constant. It can never be a function of y or z, which means that qx is not a function of y or z provided, K is independent of the directions. Well, then we can tell that heat flux is constant at all points on this area, so that I can write qx is equal to minus K Ax dT/dx.

And if this is constant at all planes because of the requirement of the steady state then one can write that this is equal to constant that means simply K Ax dT/dx is constant and that is the requirement of a steady stand one dimensional heat conduction. Now if we assume additionally that K is independent of the temperature and the direction that means the material is isotropic and its thermal conductivity is independent of the temperature or does not vary much within these range of temperature studied.

Then at the same time if we consider Ax constant, consider means the problem is defined for a plane wall that means the cross-sectional area Ax is independent of the direction of heat flow x. In that case, we can write dT/dx is equal to constant that means we get a linear temperature profile from T1 to T2 within this slab. So, therefore a steady state transfer with constant thermal conductivity with constant cross-sectional area, which happens in a plane wall, the temperature gradient is constant that means the temperature is a linear function.

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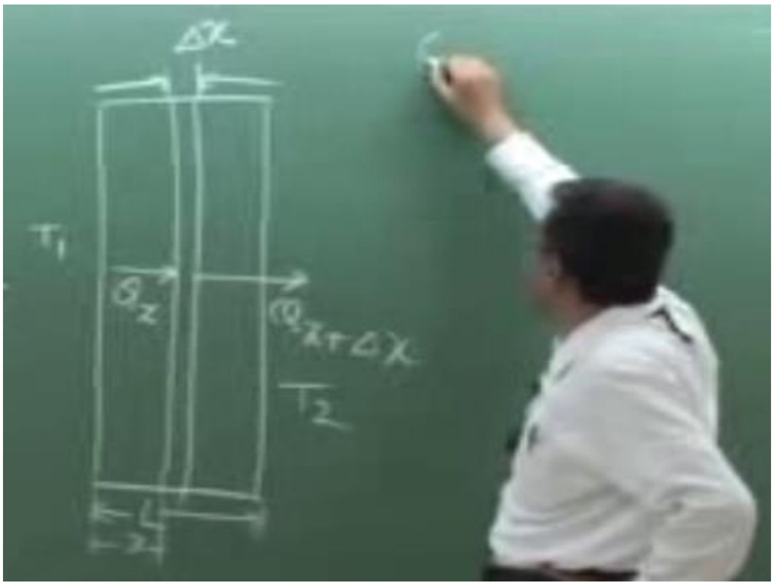

This you can also do it in this fashion in a little elaborate way I think that will help you afterwards in the deduction that you can do in this way in a separate I am showing you that if you take a small elemental volume or small element within the wall which is kept here as T1 and it is temperature T2 and at x, at a distance x, I take a small element of length delta x. Then we can it a little elaborate.

This is the most simple way of looking into it that if the total heat flux at this left side of this elemental volume is Qx and if I designate the heat out from the right phase at x plus delta x as

Qx plus delta x.

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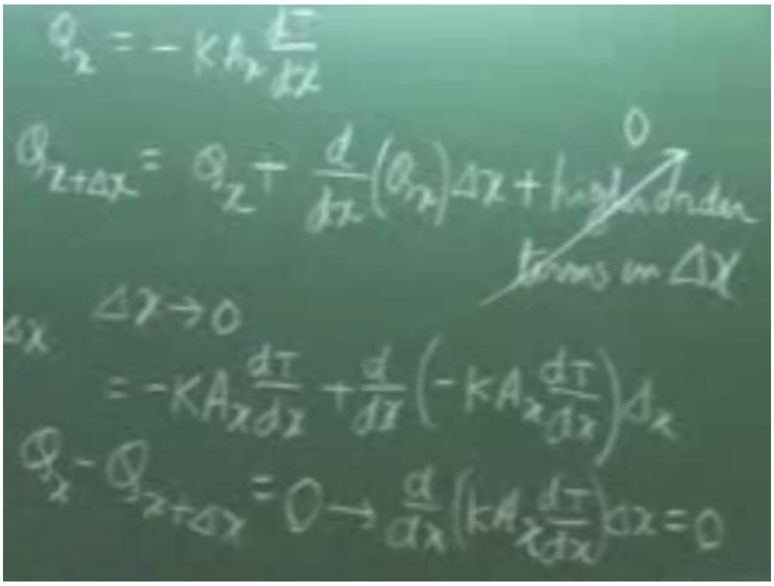

Then I can write the same thing just in a different way Qx in a elaborate way is nothing but minus K Ax because dT/dx is not a function of (()) (16:57) T is a function of x. So therefore, the same logic and Qx plus delta x, we can expand in a Taylor-series at x in the neighbourhood of x plus delta x by this way d/dx of Qx delta x plus higher order terms in delta x that means next term will be double derivative delta x 2 by 2 as you know plus going on an if delta x is very small in the limit delta x tends to zero.

In the limit delta x tends to zero, otherwise we do that neglect the higher order terms and therefore Qx plus del x is Qx that means this can be written as with the help of this KAx dT/dx plus d/dx minus KAx dT/dx into delta x. Here I have not taken into consideration that K is constant and Ax is constant. This come as a whole within the bracket d/dx that means this can change to it x.

Now if, it has to be at steady state there should not be any generation of energy within the element or there should not be any absorption of thermal energy within the element that means element will act as a transparent element whatever it receives it will allow to go out that means a steady state control volume. Influx of any material where that is mass or energy equals to the flux, so therefore, one can write Qx minus Qx plus del x equal to zero.

And if you make this thing you arrive at this same equation that this is constant means d/dx, this minus this means d/dx of KAx dt/dx del x is zero. So therefore, we get the same result that KAx dt/dx is constant, is not dependent on x though if you make this you get the result that d/dx of KAx dt/dx into del x is zero, which means that KAx dt/dx is constant okay. Therefore, the requirement for a steady one-dimensional flow is this and if Ax is constant if it is a plane wall then dt/dx is constant.

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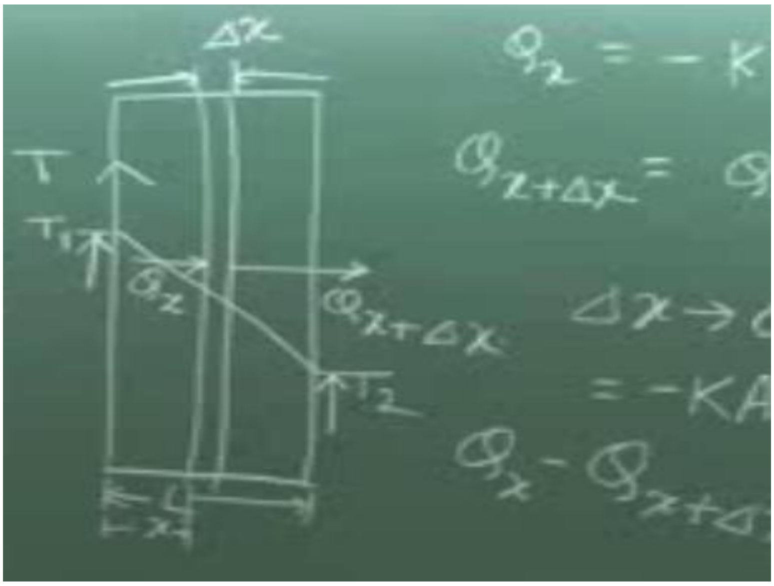

So therefore, for a plane wall with constant thermal conductivity we have a temperature, if you show the temperature scale here this is T1 and this is T2 from any reference datum so we give a linear profile. The slope of which will depend upon the thermal conductivity okay. This is clear, when we have a linear temperature profile. Now in this context, I will tell you certain things okay.

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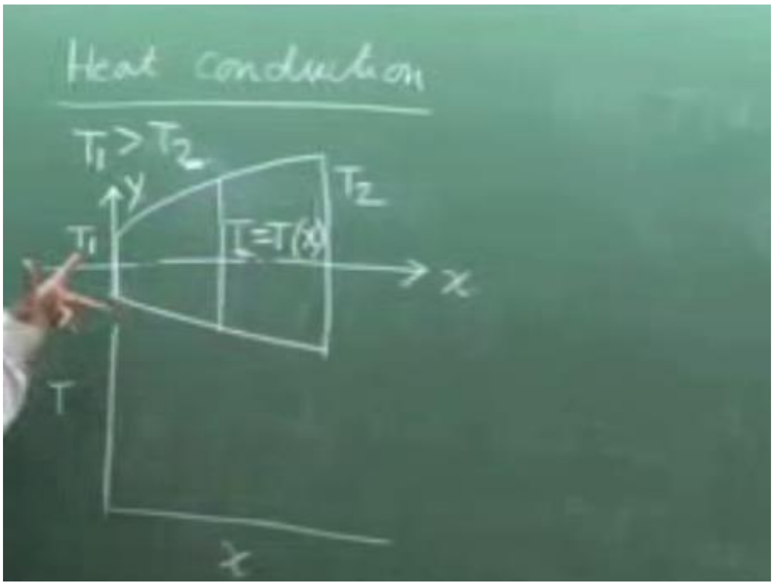

Now if we have a solid like this, whose area is not constant and if we try to conceive one dimensional steady state heat transfer by making this surface that a temperature T1, this is at a temperature T2 so that T1 is greater than T2. Then what will be the temperature variation, will it be linear, will the temperature variation at steady state one dimensional will it be linear no because area is not constant.

But one catch is here that this type of geometry which is not a plane wall that the area is not constant strictly speaking does not give a one-dimensional heat transfer picture. Usually, this type of geometry, the temperature is a function of both x and y but under certain cases the variation across this section is less as compared to the variation along the length depending upon the boundary condition.

So, what we will do, we take almost a cross-sectional average temperature T and tell it as a function of x. This is cross sectional average temperature that means it is in other word visualisation of a really truly speaking two-dimensional heat conduction as one dimensional when the variation in other direction is more. So, this happens in this type of geometry purely strictly speaking one dimensional heat conduction happens in a plane area flow.

This I will connect afterwards, after the derivation of general heat conduction equation.

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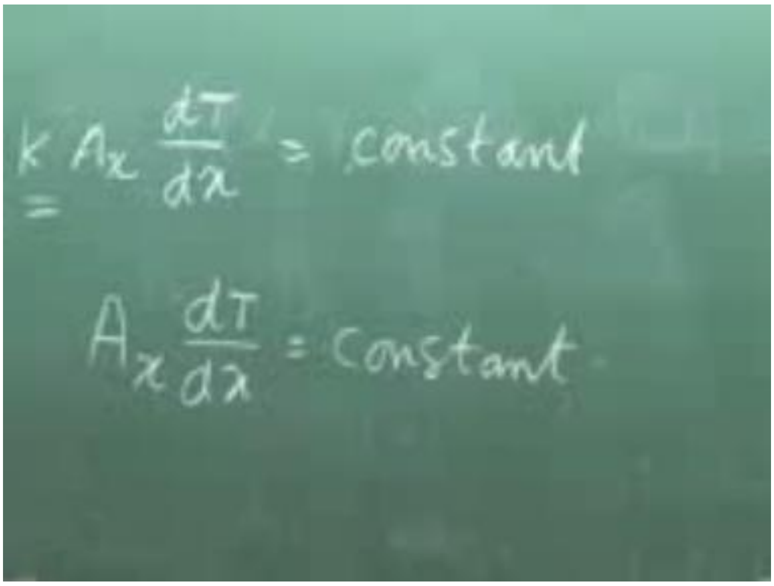

See in this case, I know my basic KAx equation for steady state is dT/dx constant not dT/dx constant. Now if K is constant that we will assume here Ax dT/dx is constant. That means dT/dx is inversely proportional to A. So, such a diverging medium a bar like this, a conical bar so that means temperature variation will be like this. This is T1, (sorry this will go like this) so this is T2.

That means the slope goes on decreasing. It is just that reverse if this is a converging bar. So, this is clear. So therefore, the essence is that KAx dT/dx is constant for one dimensional steady state transfer. K may vary, A may vary. K may be a function of temperature, since T is a function of x so K varies with temperature it will be also function of x. A may be a function of x.

So therefore, to find out analytically, the temperature as a function of x this all depends now on mathematics. So, concept of heat transfer ends here, K A dT/dx is constant. Now rest is mathematics. A very simple of the simplest case is that K constant, A constant plane wall then the mathematics becomes with the simplest thing that dT/dx is constant in a linear temperature profile okay.

So, this is just a preliminary understanding of a steady one-dimensional heat conduction, which I will come back in much more details after the derivation of general heat conduction equation. Now we come to a very important phenomenon is that convection. Well, now we come to convection, now convection heat transfer we refer to that mode where usually heat is transferred from a solid surface to a fluid adjusting to the surface, which is a motion.

Heat may go from the solid surface to the fluid, heat may come from the fluid to the solid surface. Fluid may be liquid or gases. So, direction of heat flow will depend upon the temperature difference that means it is from the hot surface to a fluid. Tremendous example, I just cite two examples, before that I tell you this type of convection heat transfer where the heat is transferred from fluid from a solid to a fluid or from fluid to solid when there is a fluid adjust into a solid surface and in motion.

The motion can be caused by two ways. One is by artificially that forced, forced flow that means we can have a fan, we can have a blower, we can have a pump depending upon the type of fluids where there it is gas or liquid to flow pass the solid surface. This is known as force convection. But even if we do not have any external aid to cross the flow because of the temperature difference because heat transfer you have to have a temperature difference.

Like (()) (28:41) to get mechanical power you have to have a delta T. Somehow with one first temperature reserver you cannot get work continuously. Similarly, you have to have a temperature difference, so because of the temperature difference a flow naturally occurs without any external aid, this arises because of the density difference and that is known as buoyancy driven flow.

That means which is caused by the difference in density and its direction is a determined by the density variation which direction the density is decreasing or increasing. So, this is known as buoyancy driven flow. As you know, if you heat something from the bottom, this becomes light at the density is reduced and this goes up and the high-density liquid comes down. So, this type of situation where the flow is induced naturally by the density difference or density variation originating from the temperature difference is known as natural convection.

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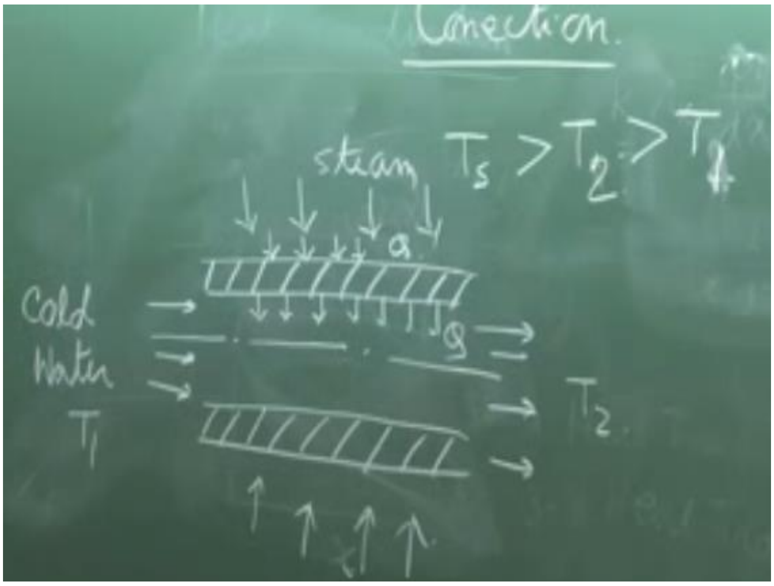

I will give two examples, consider steam condenser in a power plant. You have read power plant in thermodynamics. Let us consider a pipe through which circulating water flows. Let this is the thickness of the pipe, I am showing with little amplification or enlargement for your understanding. This is a pipe typical condenser pipe, there are a number of pipes one pie where the cold water is flowing like this.

This is cold water at some temperature T1, which is obviously the ambient temperature. We get cold water from ambience and cold water is flowing out, this is the cold water at a temperature T2 and what happens that steam from the turbine flows like this. This direction does not mean that it goes inside the tube. Tube is impermeable. This is of the metal. So, this flows around the tube.

There is a cross flow, the direction of this steam and direction of the cold water. Now what happens, try to understand because of this flow of steam, steam let us consider have a temperature Ts which is greater than T1 which is greater than T2. The steam temperature is the saturation temperature corresponding to the pressure at which we get. Any high temperature at this moment you are bothered much of the saturation state or all these things. Now first of all this heat from the high temperature steam, will heat the surface.

We use any temperature measuring instrument thermocouple or any other temperature measuring instrument we read Ts and we will see that this temperature of this surface were little less that means heat will flow from this steam to this surface and that is the mode known an convection that I will describe just after this. So, this is the convection mode. Then, heat which enters into the tube wall is a solid material it will come from this outer wall to inner wall because of which there is a difference in temperature.

That is the inner wall temperature is little lower than the outer wall temperature and that mode is pure conduction which I discussed, pure conduction. Then, what will happen the heat therefore this is the heat Q and the same heat now at steady state, the same heat will come to the inner fluid from the inner wall. Inner fluid is water. So, this is again convection. So, one convection from steam to this outer surface.

Then conduction from outer surface to inner surface to the solid, then from inner surface to the cold water heat will be transferred by it is just like a relay race. And water will carry this heat or rather advect this energy and goes out with a temperature. I am sorry, I am extremely sorry T2 greater than T1. T2 greater than T1. So, we will come out with a temperature T2, which will be higher than the T1, water will be heated.

And that is an example of force convection. Here we are causing a force flow of the water and here also steam is flowing and there a pressure difference because of this flow this is a forced convection heat transfer.

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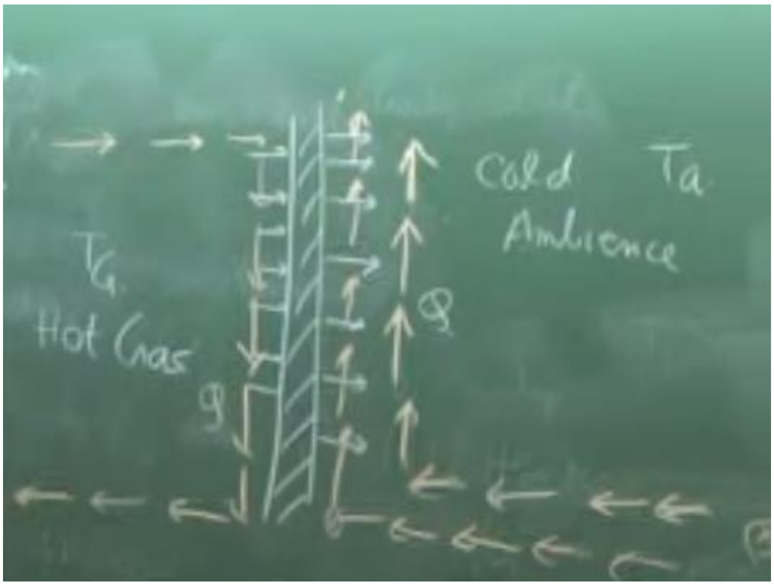

Now, another example I tell you that let us consider the wall of a vertical furnace for example the wall. Now what happen there is hot gas, usually outside cold ambience, this is temperature of the ambient is here and this is hot gas TG. The furnace wall loses its heat to the ambience. It is hot but it is cooled naturally. Sometimes, the situation is such depending upon the situation.

We do not require to flow air pasting. This is a furnace wall, this may be a circuit board of an electronic circuit, board of an electronic circuit. So, what happens here also the convection heat transfer takes place from the gas to the inner wall and the same heat is going by convection from the outer wall to the cold ambience. And here a flow is induced like this passed the surface.

A flow is induced like this, to show the flow I draw with a different colour, a flow is induced I do it by the different colour. The flow is induced like this. The white one is this. This is this colour is the flow. A flow is induced like this because of the density difference. How, you see since this is hot compared to this at any point here the pressure represents, if you consider the pressure at any higher altitude is the same at this two points, the same elevation.

So, pressure here represents a pressure over that atmospheric pressure by a height of the column whose density is at high temperature, density is low. And if you consider somewhere here in the free stream air pressure that I will explain afterwards in more detail because this is a cold air column, so at this point the pressure is relatively high because the density is high. So, this allows the air to flow like this.

This is known as chimney effect. That if you have a chimney, if you increase the height chimney you get a lower pressure at the base because of the reduction in density due to high temperature as compared to the outer ambience. So therefore, the flow is induced from the outer ambience like that. Whereas in this case it is been in the other direction because here the pressure at this point near the wall is higher than that at the free stream.

So, this way a density difference due to the temperature difference causes a buoyancy driven flow and it is known as natural convection. So therefore, convection is a heat transfer mode where heat has been transferred from a solid surface to a fluid or from a fluid to a solid surface when the fluid being adjusting to the solid surface is in motion either due to forced flow imposed on it or naturally because of the buoyancy driven flow due to the density difference.

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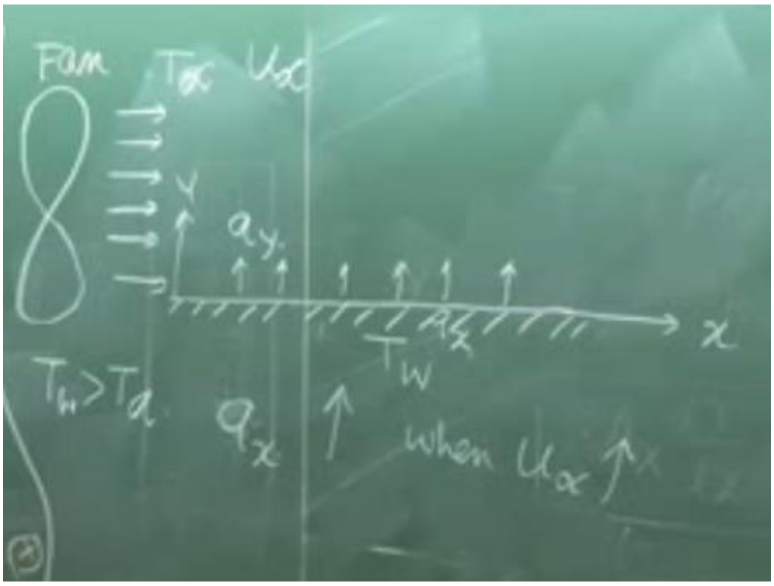

Now with this, preliminary thing in mind, I just like to tell you the convection heat transfer. Let us quantification of thus. Let us consider this practical example by a stimulation like this. Let us consider a flat plate or a flat surface. Let us consider a flat surface. These are examples a little simpler version for our basic understanding. Keep at a constant temperature Tw okay. Let us consider air, cold air flows over the plate.

And this flow is made to happen by a fan or blower and the temperature of the cold air is Ta or rather T infinite. This nomenclature I will give. The implication of it will be understood afterwards. Cold air is flowing through hot plate, this means that Tw is greater than Ta, then what will happen, heat will flow in this direction. Let us consider this as x and this direction as y so we can tell that heat is flowing in this direction.

At any point, we define this as a heat flux qy. Heat is flowing in this direction. Now if you see one thing that by our common experience we know we if increase the velocity let this is moving with a velocity uniform velocity U infinity which is coming out of the fan. Let us consider uniform velocity U infinity. Now if we increase the flow rate that means increase this U infinity velocity coming out from the fan.

The plate is cooled at a fasterly. That means rate of heat transfer increases when you increase the flow rate this is our common experience. Similar that means the heat flux if you define heat flux at any point qx, so qx increases when U infinity or the flow rate increases. So that means the rate of heat transfer from the plate to the fluid is being influenced by the flow of fluid.

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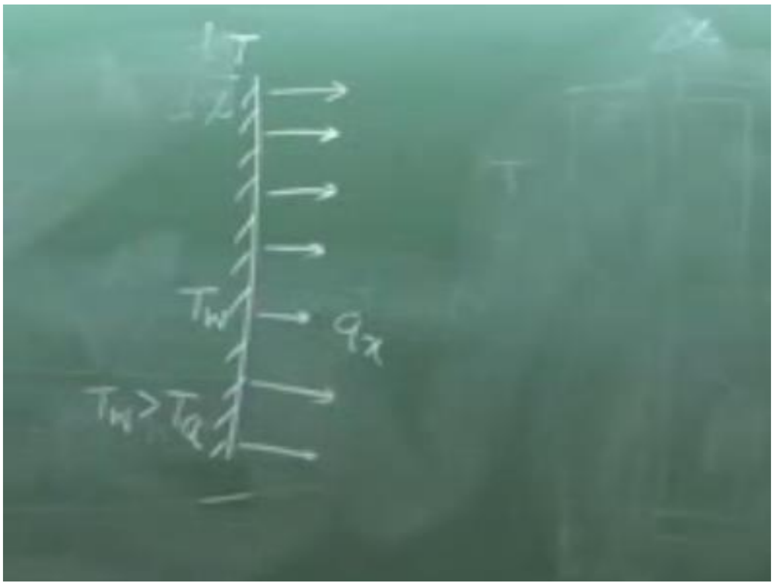

Similar is the case that when you have a vertical plate that I have told earlier at some temperature Tw where Tw is greater than Ta, the heat is transferred by convection in this direction. Here it is qx if we write the heat flux okay. Now the flow situation is like that this is a free convection case and this is a forced convection.

Now in both the cases this heat flux taking place from the surface we have to know the mechanism. What is that mechanism. First of all, we will see that this is being enhanced as the flow rate is increased.

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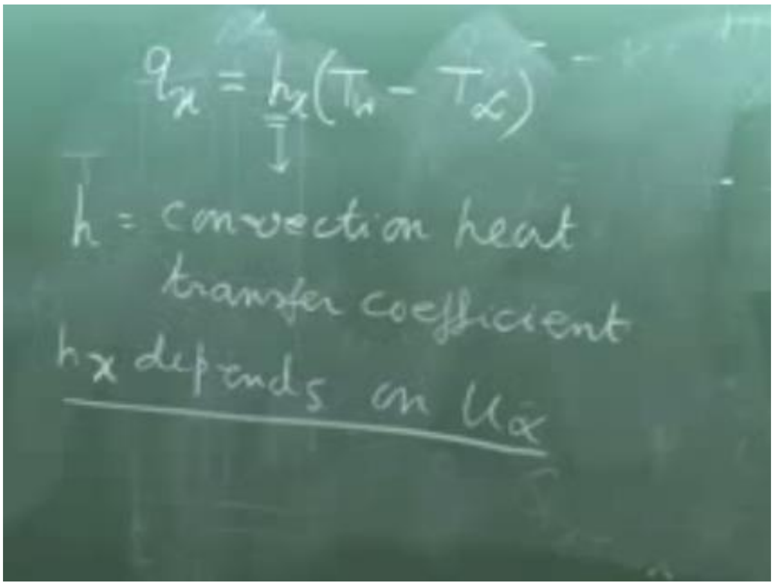

In convection heat transfer, the heat flux is defined or heat flux is determined by an equation qx in both the cases is equal to Ah into in this case Tw minus T infinity where Ah is known as convection heat transfer coefficient. Either it is forced convection, this forced convection heat transfer coefficient, it is free convection heat transfer coefficient. So qx at any point is defined as heat transfer coefficient hx at that local point hx ,all are point functions.

Tw is the temperature at that point in case of a constant temperature it will be constant and T infinity is the free stream temperature, which is unaffected by the plate. This equation defines the heat transfer coefficient. The way Fourier heat conduction define the thermal conductivity. So this way the heat transfer coefficient is defined, but to the working group who do not bother much with the concept they can find out the heat flux from this equation provided they have the information on hx, they have the information on hx.

But one interesting thing is that since heat flux increases with U infinity that means hx depends on U infinity. So hx cannot be in this situation by our common observation if you express heat flux like that do define heat transfer coefficient it cannot be a property because it is a dynamic parameter which changes with the flow rate, which changes with the velocity because if you increase the flow the heat flux is increased, plate is cooled, the surface is cooled fast.

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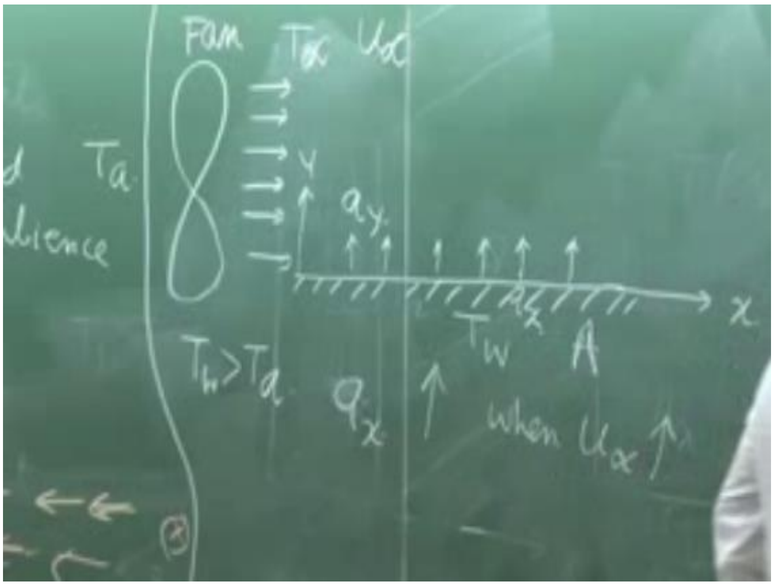

So therefore, hx depends on U infinity, it is not a property. Now this is the relationship that defines hx, the local heat transfer coefficient.

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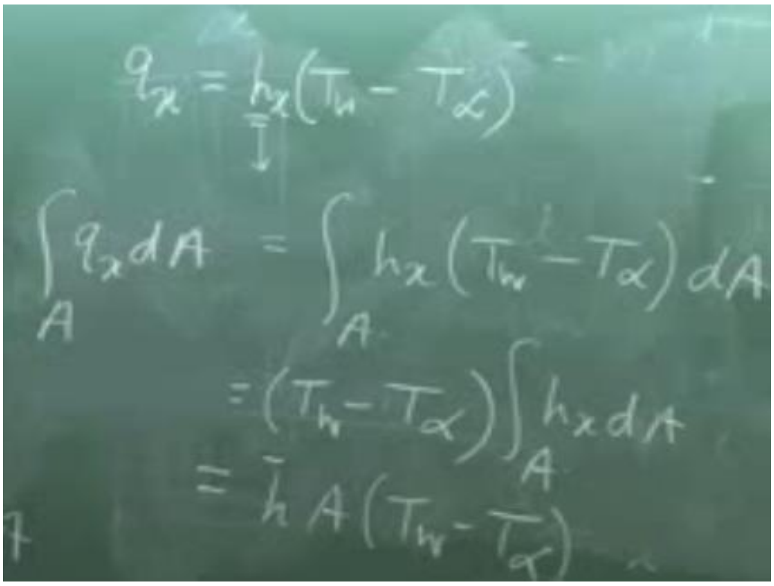

Now if you have to find out the total heat transfer from a surface of area A then what you have to do you have to integrate qx dA over the area A that means you integrate hx Tw minus T infinity times dA. Now this becomes a mathematical task if I know the variation of all these quantities with area.

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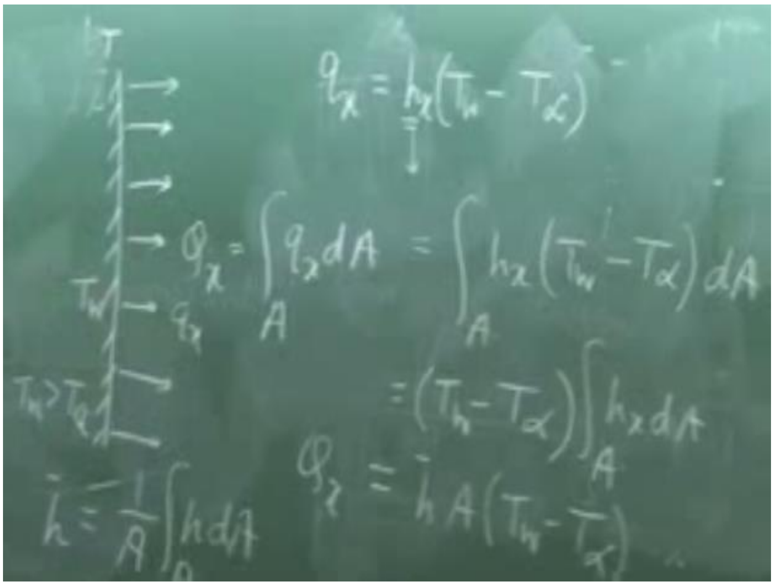

Now for this case a constant wall temperature and free stream temperature this becomes is equal to Tw minus T infinity times hx dA over the area A. Now if I define an average heat transfer coefficient over an area A as the area weighted average. Then this can be written as h bar A into Tw minus T infinity that means we can find out the total heat flux qx over an area A is the average heat transfer coefficient over that area which is defined like this because this has to be made like that integrated over that area into the area.

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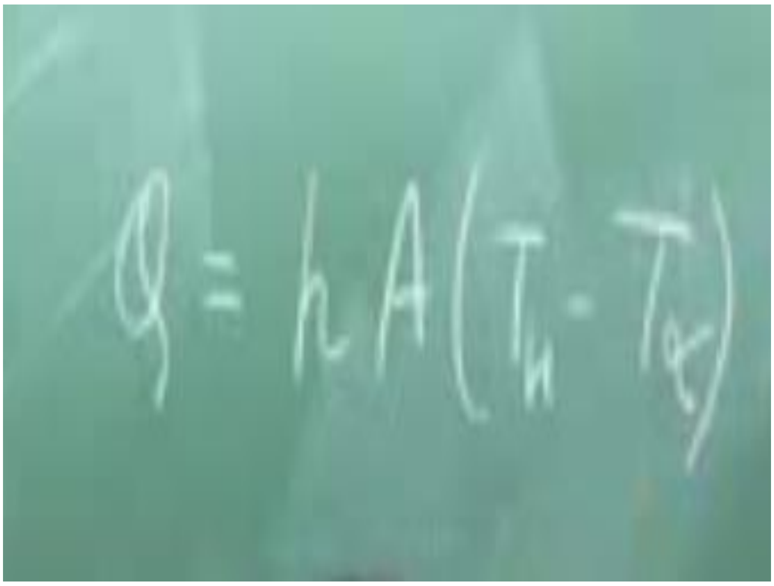

If the heat transfer coefficient becomes same constant than h bar and h is same so therefore Q’s value, we write Q is equal to hA in this case Tw minus T infinity where h is either a uniform heat transfer coefficient same over the section does not vary or in area average heat transfer coefficient h bar. But the question remains that this is a definition, this is a not mechanism. I forcefully define that convective heat flux will be h time delta T that means Tw minus T infinity.

But by doing so and clubbing with our common experience that if you increase the flow, heat flux increases we find that h is not a property that means h depends upon the flow velocity. So therefore, what is the mechanism of heat transfer from the surface to the fluid and how is it affected by the flow as to be understood and that is the central point of understanding of convective heat transfer, which I will explain you now.

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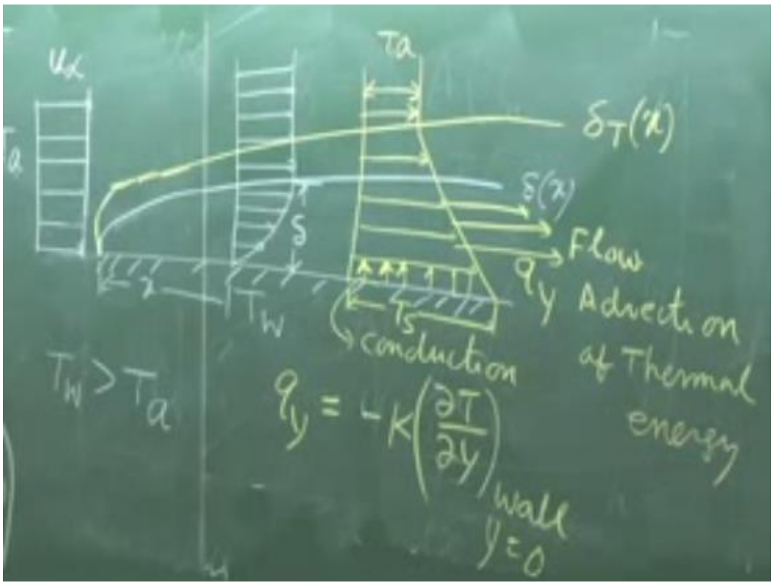

Now which I will explain you now let us consider the plate. Now to understand the mechanism consider the plate at Tw and let us assume that fluid is flowing or approaching to the plate leading edge of the plate with a velocity of U infinity. This is a recapitulation of your basic fluid mechanics concept which you have already read U infinity. And with a uniform temperature of Ta.

Now you know, when this situation happens from your fluid mechanics you know a hydrodynamic boundary layer developed, which is a function of x. What is this hydrodynamic boundary layer, that means that at any section x if you see the velocity profile, it will look like this? Recapitulating the fluid mechanics concept what happens, that the fluid velocity at the solid surface is zero related to the surface which is known as no-slip condition.

In the domain of continuum, the fluid particle cannot slip over a surface because of strong molecular addition. Under very special cases even in the domain of continuum an effective slip appears at the surface these are very rare cases in a very very small channel whose dimensions in the order of micrometer or nanometer, but usually in engineering applications except those cases and in the domain of continuum.

As you know that fluid particle cannot slip over the surface known as no-slip condition because of the addition between the fluid and the solid zero, momentum becomes zero. Then because of this momentum transport and the momentum retention relative affair between this two which is manifested through the kinematics viscosity, the fluid flow is adjusted in a way that the velocity starting from zero, no-slip condition because the plate is at zero reaches the full free stream velocity after certain distance.

Though it never reaches the full free stream velocity, it reaches asymptotically but usually we assume that after some distance where 99.5% is assumed which we take as full U infinity as the delta the boundary layer thickness and within which the velocity variation takes place and this thickness of this boundary layer depend upon the flow velocity and the liquid property and you know as a whole it depends upon the Reynold’s number of flow.

Similar is the case for the temperature because this is higher than Ta Tw is higher than Ta. So therefore, a thermal boundary layer also will be developed in these way and let us consider, I a thermal boundary layer whose we designate as delta T as a function of x and what is the implication and what is the implication of this thermal boundary layer, similar to velocity boundary layer at this section if we plot the temperature variation which I show you what the clarity here.

Here we cannot draw but at the same section we will see the temperature scale will be like temperature variation will be like this. So, this is your wall temperature Ts and this is the temp, then temperature also because of its conductivity and retention capacity by heat capacity which I will tell afterwards known as thermal diffusivity.

The temperature field is also adjusted in a way that temperature from the surface temperature in the fluid decreases after certain distance away from the fluid remains constant and this is Ta free stream temperature, cold air temperature. So, this is the picture the development of thermal. Here I have drawn a figure where delta T thermal boundary layer is higher than the velocity boundary layer.

But you do not think that it is always so, this is a particular case I have done. The boundary layer may be smaller than the velocity boundary layer may be higher than that. Both the options are there. For gases like air the thermal boundary layer is always higher than the hydrodynamic boundary layer. So, this picture is for air, for example air. So now the important thing is that at this surface there is no velocity.

So therefore, the heat which is going from the surface at the surface from solid to the surface if you consider a layer at the surface, a nanometer layer for example which is almost at rest. This heat qy can be written as qy is equal to minus K del T/del Y at the wall that means y is equal to zero. That means there is no other mode pure conduction, which is not affected by the flow because there is no flow. This is the conduction mode of heat transfer from the surface.

But what happens just above the surface there is a flow. Now this flow conflux the thermal energy, advects the thermal energy away. Because of what, the thermal boundary layer is set up that means at least some distance from the wall the fluid gets the opportunity to reach the free stream temperature because of the advection of the energy. So therefore, the temperature distribution will be affected by the advection of this flow.

And therefore, the temperature gradient will be determined by the advection of this energy flow. Advection of the flow means the advection of the energy, flow of this energy. So therefore, in this direction energy is advection of thermal energy.

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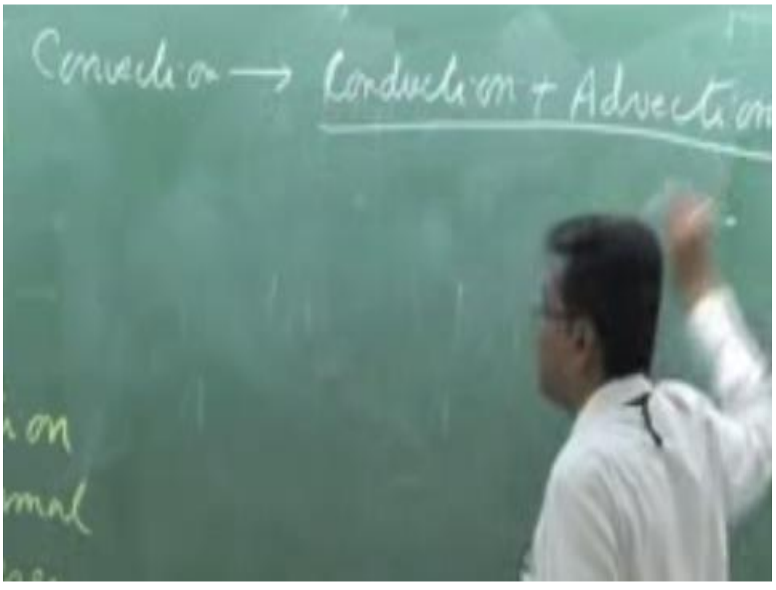

Advection convection is a phenomenon which is guided by both conduction and advection. I will do it in more detail afterwards in the introductory class of convection. Conduction and advection. Now when the flow is increased, what happen as you know from fluid mechanics concept the boundary layer will be reduced and moreover free stream velocity we will increase, which will make the velocity gradient at the wall more for which the stress is increases.

Similar is the case when the flow velocity is increased, this delta T will be reduced. That means this value of delta T, here the value of delta T is the distance from here to here. This is the delta T.

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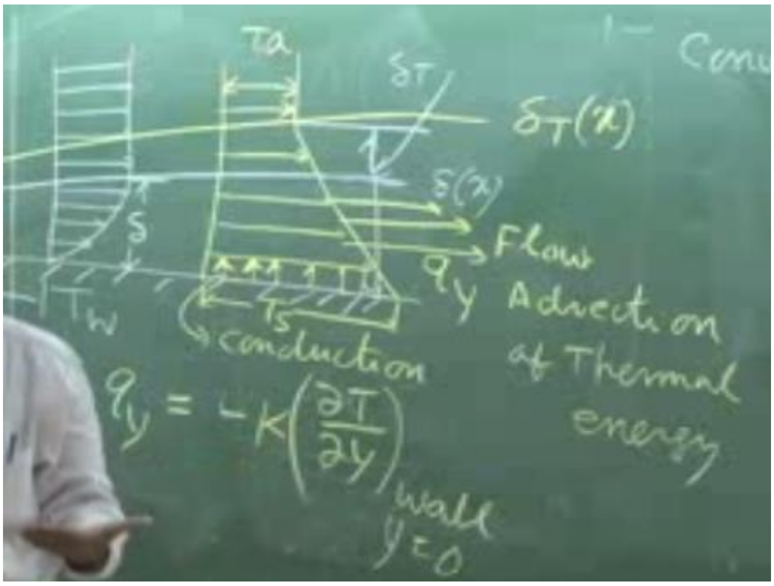

This is the, this value is delta T, this is being reduced while this is reduced mathematically you see the temperature gradient that del T, del Y at the wall is increased. You understand because the thermal boundary layer is reduced that means the fluid attains the cold temperature free stream temperature at a very close distance from the plate, but the plate temperature remains same that means the temperature curve is more steep.

This is precisely the phenomena that the flow velocity increases the heat flux and why this temperature gradient becomes steep why the fluid gets the opportunity to attain the free stream temperature at a shorter distance from the plate because the advection of thermal energy becomes higher because of the more flow. More is the advection fluid is cooled. So that fluid gets an opportunity to reach the cold temperature very close to the surface which means that thermal boundary layer is reduced.

So therefore, the conduction of heat from the surface where the velocity is zero to the fluid is totally governed by the advection of energy associated with the flow. More is the advection with the increased flow fluid gets the opportunity to be cooled quickly and gets a temperature of the cold air close to the plate by defining a thermal boundary layer. Nevertheless, at the plate.

There will be plate temperature because thermal equilibrium will be there at the plate y is equal zero, solid and fluid cannot of different temperature so therefore what happens thermal boundary layer goes thinner and thinner. Nevertheless, it becomes zero like the hydrodynamic boundary layer. So, no-slip condition at the surface with respective velocity that means it is zero because the plate is at rest and no-slip condition at the surface as far as temperature is concerned that means it is the surface temperature has to be maintained.

So therefore, with that if the thermal boundary layer and hydrodynamic boundary layer become short at due to higher flow rate both the gradient del U del Y.

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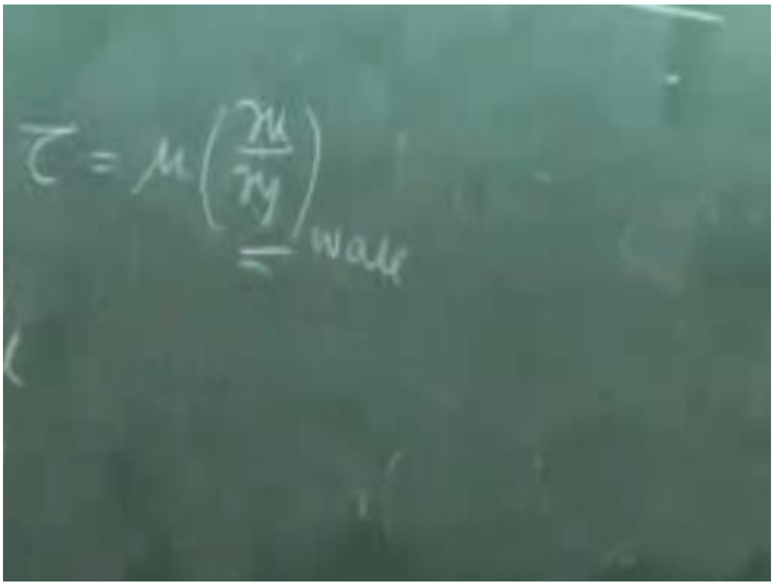

For example, in this case I can write Tau is equal to Mu del U/del Y at wall both gets increased and therefore this shear stress and the rate of heat transfers or heat flux gets increased clear. So, this is the mechanism by which flow influence the heat transfer which is basically by conduction and at the surface the only mode of heat transfer is conduction. So up to this is the introduction to convection, but again I will come back at the beginning of the convection course in more detail to give you physical concept of convection.

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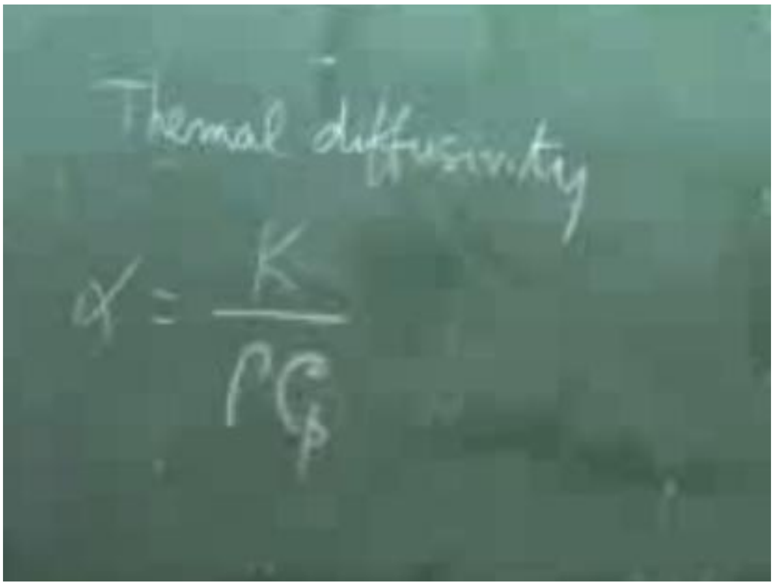

But before I end, I tell you one property known as thermal diffusivity alpha is defined as K/Rho*Cp where K is the thermal conductivity, Rho is the density and CP is the specific heat at constant pressure. Now you know that there are thermo physical properties of any physical problem related to any physical problem which can be classified into two groups.

One is the transport properties which appear in the equation showing the rate of transport of a quantity with its potential difference like thermal conductivity, like mass diffusivity, viscosity, momentum transport. It defines the momentum transport. These are the transport property whereas Rho and Cp are thermodynamic property. This is rheological property specifically.

So, the ratio of these K/Rho*Cp is known as thermal diffusivity which is an very important parameter but just by knowing the formula will not do you have to understand physical concept and implication of it. This thermal diffusivity as it is defined K/Rho*Cp you see the numerator is a property which tells how the heat is being conducted and denominator is a property which tells how the heat is or the thermal energy is stored.

So therefore, the ratio K/Rho*Cp alpha thermal diffusivity denotes the ability of a material of a medium to transport heat or conduct heat with respect to our relative to its ability of storing thermal energy. That is the physical implication a system with a very high value of alpha conducts it first as compared to storage of thermal energy and this type of material if it is put chained environment quickly respond to it in stabilising a steady temperature field well in conducting the heat.

As I told initially when I came to the class immediately class silence that means your thermal diffusivity is high whereas for the system or the material whose thermal diffusivity is low does it more sluggish that is the thermal diffusivity and here I end the introductory chapter.

Next class we will deduce the heat conduction equation in general that means that will give you the basic governing equation relating the temperature with the space coordinates and time for conduction heat transfer and which will be derived from by utilising the principle of conservation of energy and that part will be taken by Professor Suman Chakraborty in the next class or in the next session, okay. Thank you.