Fundamentals of Food Process Engineering

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Lecture – 11
Thermal Processing and Kinetics of Microbial Death

Hello everyone, welcome to online certification course Fundamentals of Food Process Engineering. We have completed the first chapter, which was on food geology. Today, we will start a new chapter on thermal processing and kinetics of microbial death.

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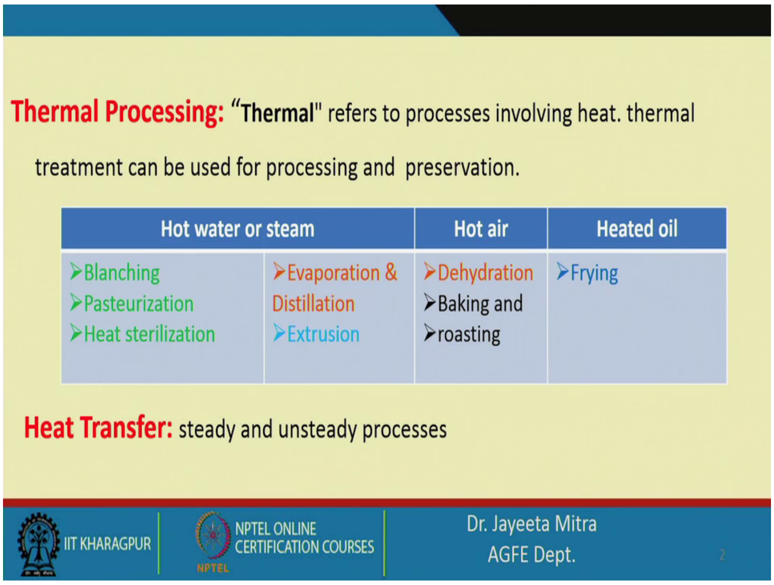

Thermal processing, by thermal processing, we means any sort of food processing involving heat ok. So, thermal treatment can be used for either processing that is for conversion of raw material to a desired food and also thermal treatment can be used for preservation ok.

So, let us see description of how we can divide this thermal processes; although, there is many thermal processes, but the common processes are if we use hot water or steam for processing, that is blanching pasteurization and heat sterilization. There are also evaporation and distillation and extrusion, which is can be done using the hot or steam. The heating operation in this, processing can be done by hot water or steam, there are also certain processes, where hot air is involved like dehydration or drying, baking, roasting some processing, where heated oil is used as for example, frying.

So, all such treatments can be come under the thermal processing, but if we consider the first three that is blanching pasteurization and heat sterilization. These three is used for preservation of food materials. So, in this course, we have designed a separate chapter on evaporation and distillation and also on drying. So here in this chapter the thermal processing and microbial death kinetics; we will discuss only the preservation techniques; that is being used by application of heat.

Now,, when we talk about heat transfer, we know that there are two modes that either steady state or unsteady state, heat transfer in certain food processing operation. We use the steady state heat transfer ok; that means, whatever heat is coming into the system or the control volume. We are discussing and the same amount of heat, the same rate of heat is going out of the system ok.

So, most of the processes where we do the continuous operation; let us say for example, a heat exchanger ok, which is continuously operating and the conditions of the two fluid that are used in the heat exchanger is, is being constant like the inlet temperature of, inlet temperature of a milk that is entering in a heat exchanger and the outlet temperature is maintained constant and also the other fluid, which is used to, cause the heat transfer.

So, that is also inlet and outlet temperature is maintained constant. So, in such process what happened that we eventually reach a equilibrium state or a steady state and at the steady state operation, the whole process continues. So, in such cases we, we generally considered the steady state heat transfer, but in, in certain cases where unsteady process are very important, because some processes, some food process, techniques are such that we eventually stop the process, when the centre point reaches at a particular temperature. For example, here we have mention, mentioned that heat sterilization which is a thermal processing, which is the preservation technique.

So, in that normally suppose, we want to sterilize one can of food. So, we want to see that the centre temperature should reach the desired temperature level or the set temperature at which we want to perform the sterilization. So, in that case starting from the initial temperature to the final temperature, that is being designed the food has to attain that temperature over, over a duration of time.

So, in such cases the unsteady state heat transfer is required ok. So, all though, in your heat transfer, subjects maybe this steady and unsteady state, heat transfer will be covered, but, we want to give here some basic idea of this unsteady state heat transfer. So, that the further processing in this, thermal processing that we will discuss like blanching pasteurization and heat sterilization will be clear to you. So, next we will discuss about the unsteady state heat transfer process ok.

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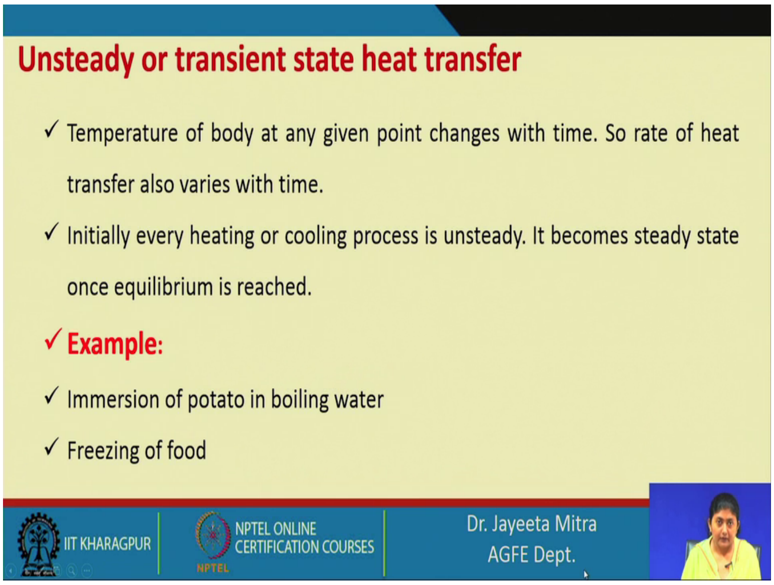

So, unsteady state or transient heat transfer, we call this as unsteady state heat transfer, because the temperature of a body at a given point changes with time. So, rate of a transfer also varies with time. So, what happens that in, in this kind of material in this style of heat transfer.

Initially, every heating or cooling process is unsteady as I said that initially, we start the unsteady state and eventually, we reach an equilibrium condition and that is considered as the steady state heat transfer.

For example, if we discuss the immersion of potato in a boiling water. So, potato, must be having an initial temperature, which is, with respect to the ambient temperature. Let us say T 0 and when we immerse it in into a boiling water, the temperature may be near 100 degree. So, then it attains that temperature gradually. So, this attainment follows, the unsteady state first unless, it reaches the, equilibrium condition.

Similar case happened for freezing of food. So, when we start freezing it, first from the, from the outside generally, because we do the freezing by exposing the food sample to chill air very-very cool environment. So, gradually this unsteady state, heat transfer starts to happen in the, in the, in the food material and then gradually it reaches the steady state condition.

So, we know that the basic heat transfer equation, when we frame for any system. We the things, we need to consider is the rate of heat transfer, rate of heat coming into the system plus any rate of heat generation, into the system will be equal to the rate of change of heat content of the system plus the rate of outflow of the heat from the system and here we will see that.

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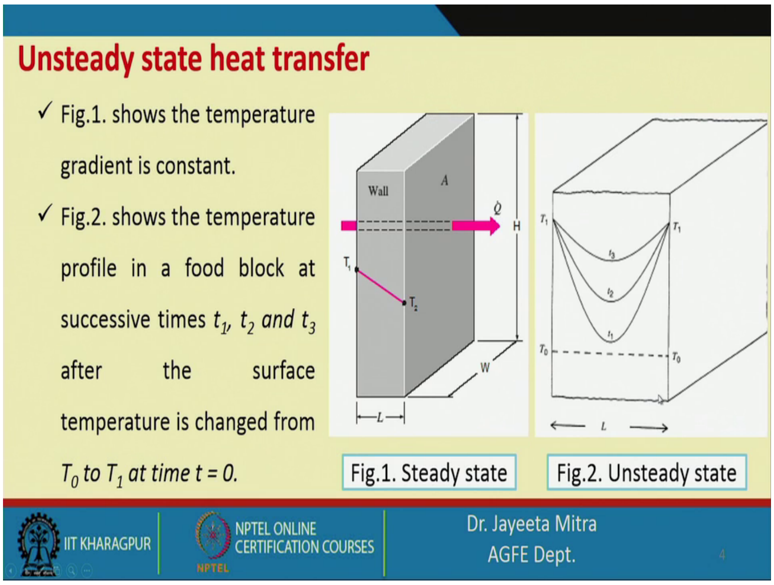

When we have reached the steady state ok, then we can see in this, in this picture where ok. So, in this picture we can see that its a slab of thickness L and width W height H through this Q dot amount of heat is flowing from the side where the temperature is T 1 to the other side where the temperature is T 2, because the gradient is from T 1 to T 2 as T 1 is higher temperature than T 2 a is the heat transfer area across which the heat flows.

Now, here the steady state has been arrived; that means, whatever Q dot is coming into the same amount of Q dot is going out no accumulation is there, neither the heat generation within the wall. So, what happened the temperature profile will remain constant and so is the heat transfer; however, if, if we consider the other slab which is just beside this, where again L is the thickness across which the heat transfer is taking place. So, if we consider this as the direction x, the other two direction y and z are maybe infinite length, maybe of infinite length.

So, what happened that if the initial temperature of this block is maintained at T 0. So, the whole system having the temperature of T 0. So, T 0 in both the side of the block remain constant. Now if this block is suddenly plunged into a higher temperature which is T 1 ok. If this is dropped into a plunge into a sink of having a higher temperature T 1, then the surface will attain the temperature T 1 instantly. If the surface convective heat transfer coefficient is very high and what happened the internal structure that eventually with time the material will try to attain the temperature T 1. So, this profile which was earlier flat will try to change this way, unless it again will reach an equilibrium condition. So, this thing that the temperature profile is varying from T 1 T 2 to T 3, this is because of the unsteady state heat transfer.

So in this case the temperature profile is not constant and also the heat transfer that is coming into the system, the rate of heat transfer will not, will be the same that that is going out of the system. So, there will be a difference between that, because some accumulation will be there. So, as it will try to equilibrate with the ambient temperature.

So we have seen that how with successive time t 1 t 2 and t 3 after the surface temperature changed from T 0 to T 1 at time t equals to 0, the block will try to equilibrate the temperature within it.

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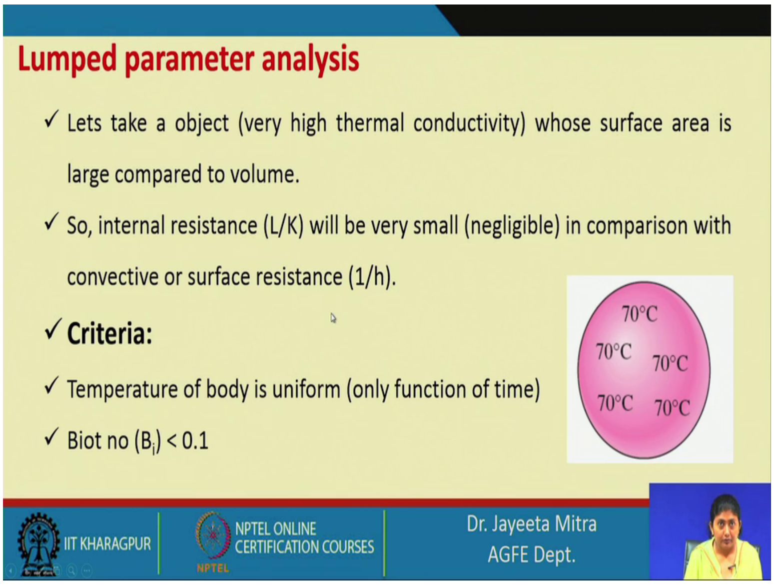

So, because of that a concept is introduced in this unsteady state heat transfer which is called the lumped parameter analysis. So, lumped parameter analysis, we will see that it will be applicable for certain cases where we have some consideration of the geometry of the material.

Here we will also introduce a dimensionless number that is called the biot number. So, biot number is represented by the internal conductive resistance divided by the external convective resistance. So, lets take an object which is having very high thermal conductivity; that means, very low internal conductive resistance whose surface area is large compare to volume. So, internal resistance; that is L by K will be very small or negligible in comparison with the convective or surface resistance that is represented by 1 upon h, which is convective heat transfer coefficient at the surface ok. So, since the conduction is very high we can see that if this is the material, everywhere the same temperature prevails. So, temperature of the body is uniform that is only function of time.

So, the criteria as I said that biot number, which is the ratio of internal conductive resistance L by K to the external convective resistance 1 by h. So, this can be represented as L by K divided by 1 by h. So, h into L by K biot number should be 0., so that we can consider this case as lumped parameter method

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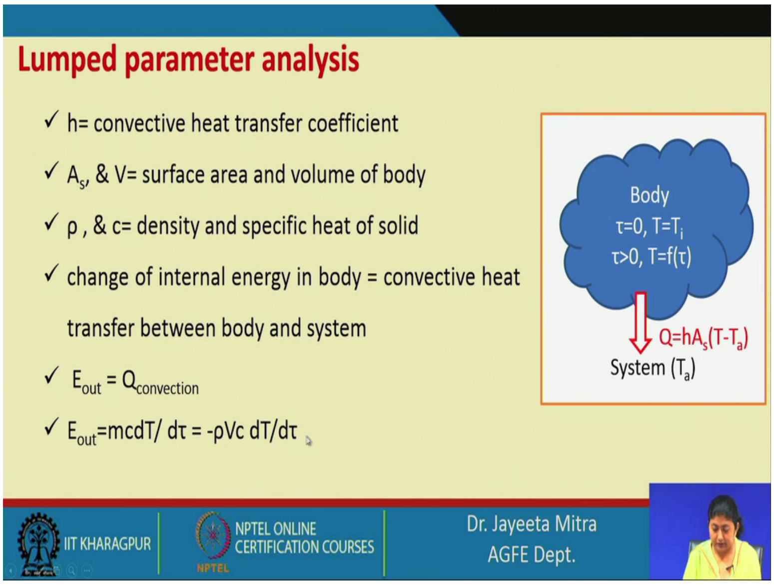

So, in case of lumped parameter analysis, as I said that initially when body was a fix temperature, where T equal to T i when time t equal to 0 and when time t greater than 0, Ts will be function of time. So, when this body is plunged into a sink having a temperature T a ok. So, heat will come out of the system. If this T a is lower than the body temperature or else if this T a is higher than this. So, this body will gain temperature and that temperature that that heat that will come out, can be represented as h into A s into T minus T A, h is the surface convective heat transfer coefficient, A s is the surface area of the body, T is the temperature and T a is the system temperature or the sink temperature

V is the surface area. Sorry V is the volume of the body and rho and c are the density and specific heat of the solid or the other material. So, change of this internal energy in the body that will be equal to the convective heat transfer between the body and the system. So, what will be the change of internal energy. So, the internal energy change will be m into specific heat into d capital T; that is temperature by d of small t; that is time or we can write it as rho V c d T by d tau or small t, if we can represent this by time and we can equate this with the convective heat transfer.

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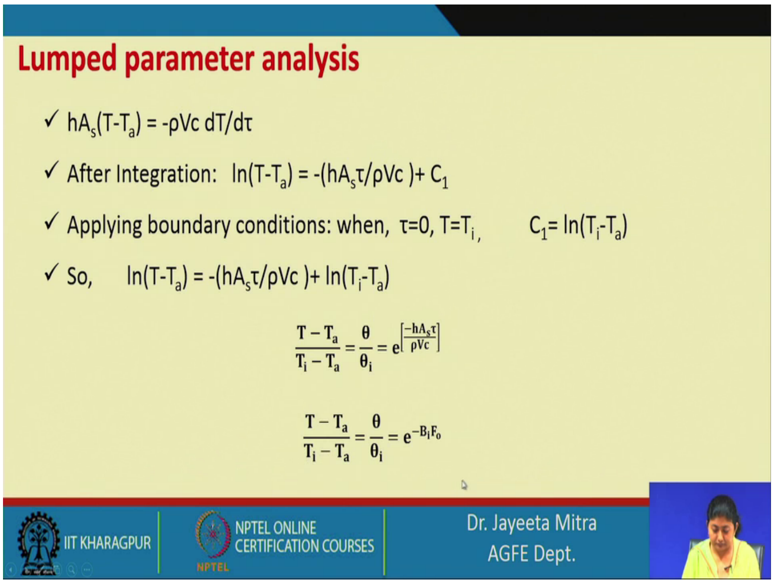

So, finally, we are getting this h into A s into T minus T a; that is equal to rho V volume of the body c, that is specific heat of the body into temperature, change of temperature with respect to time and we can integrate this equation. So, that we can get this term l n T minus T a; that is equal to minus h into A s into tau; that is time by rho into V c plus C 1

Now, we can introduce the boundary condition here. So, the boundary condition will be when time equal to 0 temperature was T i initial temperature, and putting this we are getting the value of C 1 as l n T i minus T a. So, this equation will become l n T minus T a; that is equal to minus h A s tau or time by rho V c plus l n T i minus T a which can be further written as T minus T a by T i minus T a; that is equal to theta by theta i that is equal to e to the power minus h A s tau by rho V c

So, this can be further written as this e to the power minus h A s by h A s into T by rho V c, that can be also represented in terms of two dimensionless number; one is biot number B i, another is the Fourier number F o, you biot number we have discuss and Fourier number you may be knowing, because in the heat transfer it is been covered Fourier number is expressed by alpha T by l square or x square, which is the characteristic dimension of the geometry that on which we are doing this analysis.

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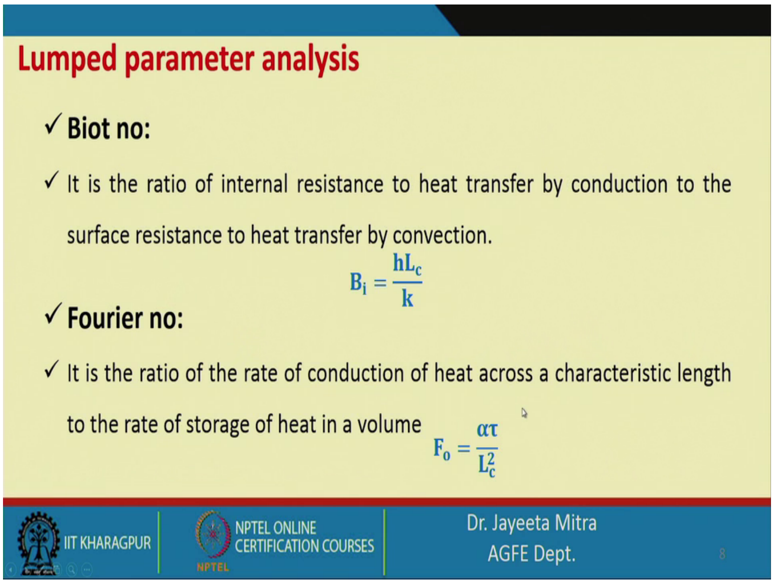

So, biot number as I said, this is the dimensionless number which is representing the ratio of internal conductive resistance to heat transfer divided by, divided by the external convective heat transfer resistance. So, h into L c by k and Fourier number, the ratio of rate of conduction of heat across the characteristic length to the rate of storage of heat in a volume. So, that is F 0 equal to alpha T by L c square

So, alpha is again k by rho c p. So, k into T divided by dimension L c; that is the rate of conduction of heat across a, characteristic length divided by rho c p into V. So, that that is giving the expression of the storage of heat in a volume. So, this two dimensionless number which is very useful in case of unsteady state heat transfer, because based on that we can finally, determine the transient heat transfer or the temperature profile with time in case of any food material.

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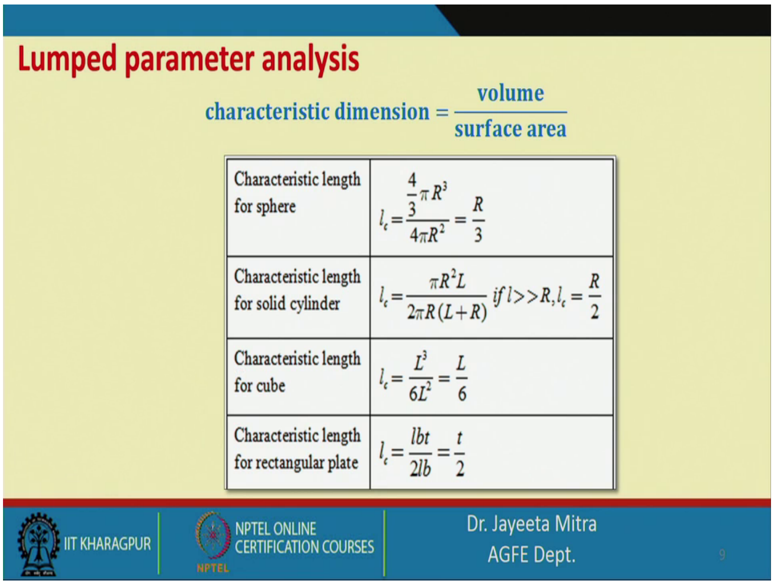

So, we are talking, talking about the characteristic dimension in these numbers, in the biot number. So, this characteristic, characteristic dimension is actually represented as volume by surface area. So, we know that biot number should be less than 0.1, so that we can apply the lumped parameter analysis on this kind of system. So, for that the characteristic length of sphere; that is l c will be equal to volume of a sphere 4 by 3 pi R cube divided by the surface area 4 pi R square. So, R by 3, where R is the radius of the sphere.

Similarly, for characteristic length of cylinder made of a solid food l c will be pi R square L; that is the volume by 2 pi R L plus R, if l is much much greater than R. So, then lc will be equal to R by 2 and characteristic length for cube will be L by 6 characteristic length for rectangular plate l c; that is equal to length breadth and thickness divided by 2 into length and breadth that is equal to thickness t by 2. So, these l c we will use in the biot number; that is h into L c by k for calculating the biot number for these cases, in case of unsteady state heat transfer.

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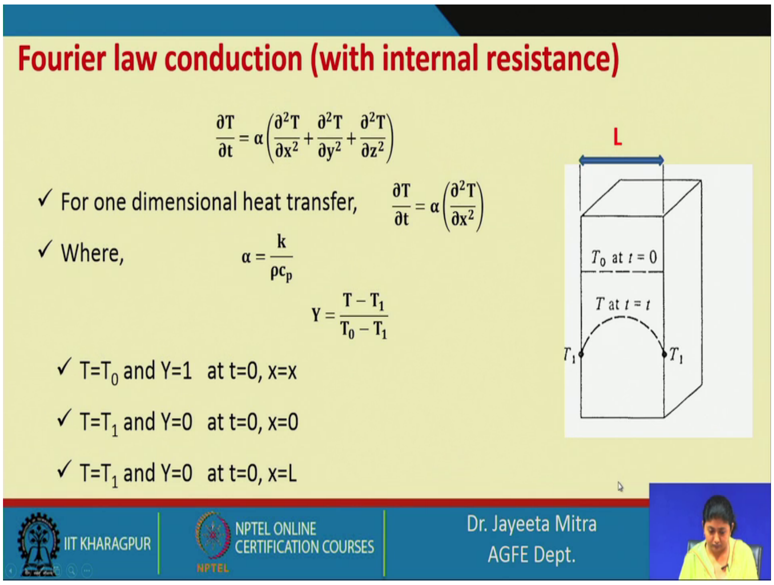

Now, next we will consider the Fourier's law of heat conduction for those material where the internal resistance exist, because the first case we have considered where the internal conductive resistance is negligible; that means, the thermal conductivity is very high. Now we will see the case with internal resistance. First we are taking the Fourier's law of heat conduction.

So, this is the unsteady state Fourier's law of heat conduction in three direction. So, here we are considering the generation of heat, rate of heat generation or heat accumulation is 0. So, temperature change with respect to time will be a constant alpha into the heat conduction in different direction; that is 3 dimension, it is a 3 dimensional case. So, three different direction x y and z this will be the equation.

Now, if we neglect the heat transfer, conductive heat transfer in the other two direction; that is y and z, only we consider the x directional conductive heat transfer. So, this equation will reduce to delta capital T by delta small t; that is equal to alpha d square T by d x square and we also can think about that alpha. Here we have taken constant alpha is equal to k by rho c p, where k is thermal conductivity of the material by rho is the density and c p is the specific heat of that material. So, we consider here alpha has constant.

So, in this block we can see that how the temperature will change when the internal resistance is present. So, T 0 was the temperature of this block, which is where we are considering only x directional heat transfer and in the y and z direction we consider the neglect, we are neglecting the heat transfer there. So, T equal to 0 T 0 was the temperature and if we drop this block in a temperature in a low temperature sink. So, it try to reduce the surface will come instantly to t 1, but because the internal conductive resistance exists, it will move to the equilibrium state in an unsteady process.

So, here we will consider a dimensionless temperature parameter to solve this equation, that parameter is Y; that is equal to T minus T 1 by T 0 minus T 1 T 0 is the initial temperature of the block and T 1 is the temperature of the outside sink or surrounding T is at any instant temperature variation; temperature of the block. So, if T equal to T 0, y will be equal to 1 and at time T equal to 0. For all x this will be valid, because when T equal to 0 that is initial condition. So, the whole block was at a temperature T 0; therefore, at any x this will be valid.

Now, if suddenly this is plunged into a system of temperature T 1. So, x equals to 0, the temperature will attain T 1 and Y become 0 also at x equal to l that towards x direction the extreme end at T equal to 0, also become temperature is equal to T 1 and Y become 0.

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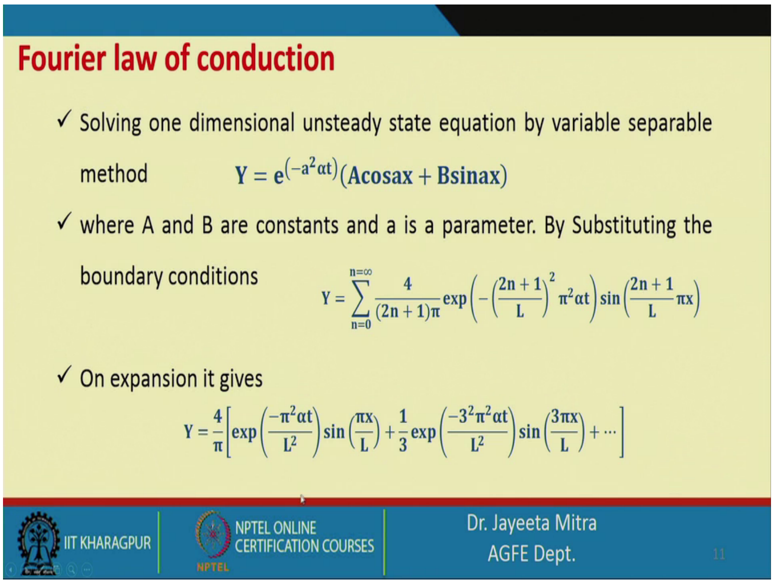

So, solving that one dimensional case; that is this equation delta T by delta small t that is equal to alpha d square t by d x square with these boundary condition and taking Y equal to T minus T 1 by T 0 minus T 1 we are getting.

First the Y equal to e to the power minus a square alpha t into a cos a x plus b sin ax, whereA andB are constants and a is a parameter. Now putting those boundary condition the those were listed in the earlier slide, we are getting that Y is equal to summation n equal to 0 2 n equal to infinity 4 by 2 and plus 1 pi exponential minus 2 n plus 1 by L whole square into pi square alpha t sin 2 n plus 1 by L pi x. So, here putting n equal to 0 1 2 we can get the terms and we can also, we can find those terms, but eventually we have seen that in the, in the study that these terms except the, except the first term does not significantly contribute to the calculation of the temperature profile ok, unless the temperature of the of the sink and the body is very close.

So, that is why most of the time we consider the first term only that is putting n equal to 0. We are getting 4 by pi exponential minus pi square alpha t by L square sin pi x by L ok. So, most of the cases we will consider the first term or we can check with the second term, as well as we are teaching to the how much we can reach to the accuracy.

So, we will stop here and will continue this topic only in the next class.

Thank you.