Electronics Enclosures Thermal Issues

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Lecture – 08
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Hello, so allow me to continue, what I have spoken in the earlier thing was again a little big bit from (Refer Time: 00:26) textbook, a little more from Ransburg book on this electronic heat management, and I have already shown you some heat things which are taken from the lab which incidentally are commercially used some may be old and I may not be appropriate. So, let me get back to the book again.

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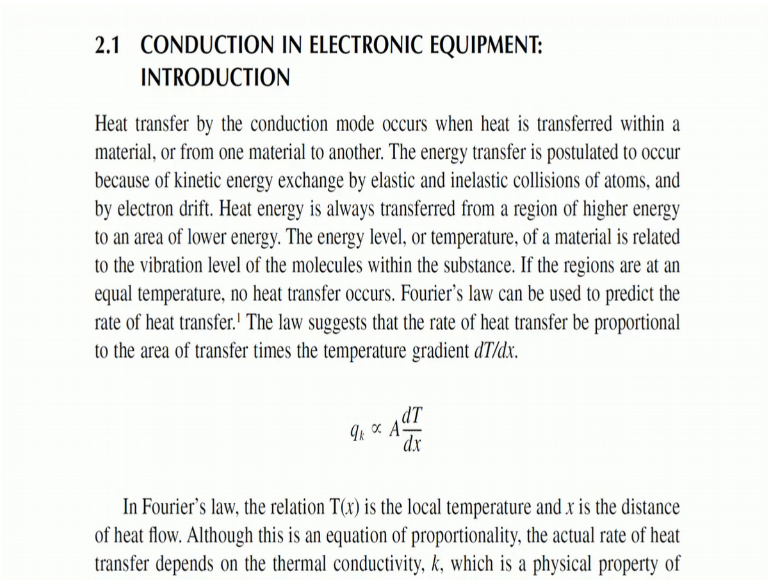

2.1 CONDUCTION IN ELECTRONIC EQUIPMENT: INTRODUCTION

Heat transfer by the conduction mode occurs when heat is transferred within a material, or from one material to another. The energy transfer is postulated to occur because of kinetic energy exchange by elastic and inelastic collisions of atoms, and by electron drift. Heat energy is always transferred from a region of higher energy to an area of lower energy. The energy level, or temperature, of a material is related to the vibration level of the molecules within the substance. If the regions are at an equal temperature, no heat transfer occurs. Fourier's law can be used to predict the rate of heat transfer.[1] The law suggests that the rate of heat transfer be proportional to the area of transfer times the temperature gradient dT/dx.

$$q_k \propto A\frac{dT}{dx}$$

In Fourier's law, the relation $T(x)$ is the local temperature and x is the distance of heat flow. Although this is an equation of proportionality, the actual rate of heat transfer depends on the thermal conductivity, k, which is a physical property of

And why you may be wondering why I am reading from the book it is not about reading from the book. It is that you shouldn't see the original whatever which has been written down understand it the moment it passes to 2 or 3, it will only be retrieved previously and I said kindly I acknowledge, the good work done by the authors and I expect that you by the book are contribute acknowledged, and also get one for your library or for yourself personally it is worth it.

Now, let me get on with the lecture, I am repeating what has been done earlier. So, you see here I will just point out because there is no mouse in this case if the regions are at equal temperature know heat transfer occurs Fourier's law can be used to predict the rate of heat transfer. The law suggests that the rate of heat transfer, proportional to the area of transfer times and temperature gradient, seen this know this what I have stable telling you area one is area here and temperature gradient.

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of heat flow. Although this is an equation of proportionality, the actual rate of heat transfer depends on the thermal conductivity, *k*, which is a physical property of the heat transfer media. Thermal conductivity is generally expressed in terms of W/m K.

Heat transfer can occur by conduction through any material: solid, liquid, or gas. Conduction cannot occur through a vacuum because there is no material to conduct through. Conduction is not usually the predominant method of heat transfer through a gas or liquid. Usually, as we apply heat to a fluid, the heated portion of the fluid expands and sets up density gradients. These density gradients cause motion within the fluid, which leads to convective heat transfer. Convective heat transfer, a macroscopic method of energy transfer, is much more effective than conductive heat transfer.

The values used for the thermal conductivities of liquids and solids are generally obtained by experimentation. The thermal conductivity of gases at moderate temperatures closely follows the kinetic theory of gases, and therefore calculated values may be used.

This is where you need to read reread what is already written the thermal conductivity is generally expert express in terms of watts per meter, meter is a running length starting from the beginning to end understand know in the direction of I will used the what heat flow or in the direction of the energy transfer.

So, again I am trying to get you back to the old physics experiment, where you have a can and then you have three pins of different conductivity. They are coated with wax and then there is a small slider when you put a hot fluid they start heating and you see that slowly, the sliders will come down the one which has highest conductivity that is copper they will go all the way down. In between usually iron is used or iron means now you only get mild steel and then occasion is the third will be some non conducting material where it does not move at all, but it does move a little.

So, coming back to the this thing here we have the relation is local temperature, the actual rate of heat transfer depends on conductivity, which is a physical property of the heat transfer media. And this is the next thing heat transfer can occur in any material solid, liquid or gas conduction cannot occur through a vacuum, conduction it not usually the predominant method of heat transfer through a gas or liquid.

Seen here heated portion of the fluid expands and sets of density gradients, in my earlier lectures, I have told you, I have given you a practical example of when you see thermals rising above any hot surface. So, right from a distance you can make out that if it is an exhaust pipe you can see that the view behind is slightly distorted because the air is hot gas and if you practice yourself you can easily make out where is the source and so on.

So, and then extreme example is seeing a mirage, where in the desert sign there are tremendous amount of this you know heating and a thirsty person sees what looks like water and I said the other pictures which you will see in the cartoons are only a little bit of imagination what he sees is what looks like water. Convective heat transfer a microscopic matter of energy is much more effective than conductive heat transfer the values used for thermal.

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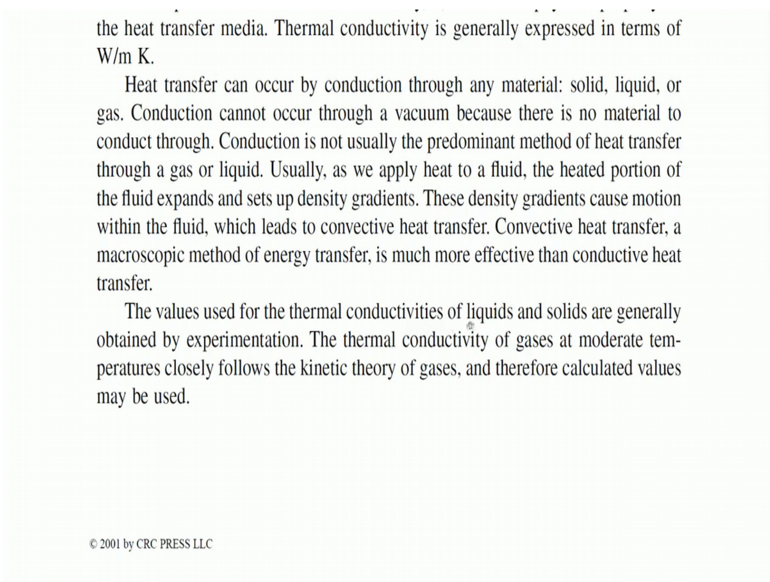

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The values used for thermal conductor is liquid and solids are generally obtained by experimentation, the thermal conductivity of gases at moderate temperature closely follows the kinetic theory therefore, calculated values may be used now seen this here most important here this what I wanted to tell you it is about the issue is about experimentation.

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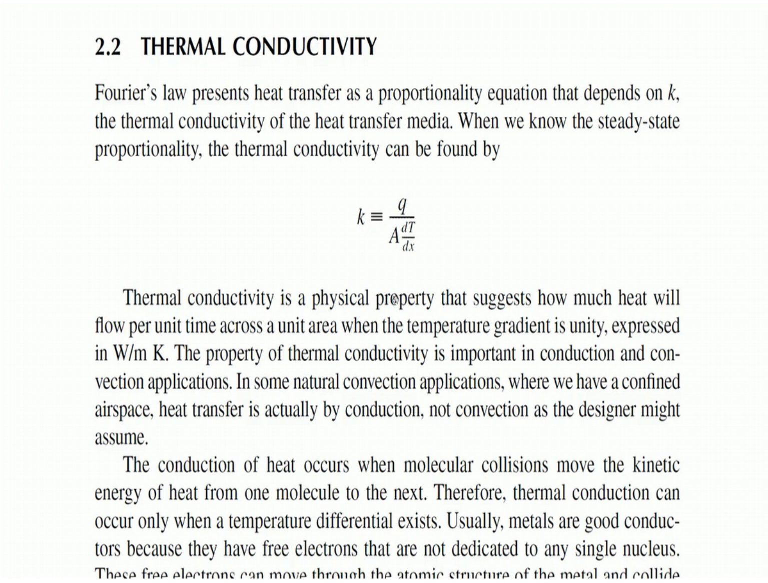

2.2 THERMAL CONDUCTIVITY

Fourier's law presents heat transfer as a proportionality equation that depends on k, the thermal conductivity of the heat transfer media. When we know the steady-state proportionality, the thermal conductivity can be found by

$$k \equiv \frac{q}{A\frac{dT}{dx}}$$

Thermal conductivity is a physical property that suggests how much heat will flow per unit time across a unit area when the temperature gradient is unity, expressed in W/m K. The property of thermal conductivity is important in conduction and convection applications. In some natural convection applications, where we have a confined airspace, heat transfer is actually by conduction, not convection as the designer might assume.

The conduction of heat occurs when molecular collisions move the kinetic energy of heat from one molecule to the next. Therefore, thermal conduction can occur only when a temperature differential exists. Usually, metals are good conductors because they have free electrons that are not dedicated to any single nucleus. These free electrons can move through the atomic structure of the metal and collide

Without experimentation or trying to establish the actual, what you call conductivity coefficients in actual use trying to extrapolate may not be that effective are useful, because even surface characteristics and the way are things are mounted and the way things are oriented all of them now seem to make tremendous amount of impact.

Now, coming back to my this thing Fourier's law presence heat transfer as a proportionality equation steady state proportionality thermal conductivity can be found as k is identical to all these things here, the property of thermal conductivity is important in conduction.

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assume.

The conduction of heat occurs when molecular collisions move the kinetic energy of heat from one molecule to the next. Therefore, thermal conduction can occur only when a temperature differential exists. Usually, metals are good conductors because they have free electrons that are not dedicated to any single nucleus. These free electrons can move through the atomic structure of the metal and collide with other electrons, or with the larger ions and nuclei within the structure. The identical mode of energy transfer also occurs during electrical conduction. This is why most materials that are good thermal conductors are also good electrical conductors. The primary exception to this is diamond. Diamond has a thermal conductivity value approximately 5 times higher than copper, but a dielectric strength 10 times higher than rubber.

2.2.1 Thermal Resistances

Often, the thermal resistances characterize the transmission of heat in the path of heat transfer. Examples of this include thermal pads, dielectric insulators, and adhesive bonding materials. Thermal resistance is most often expressed as temperature rise in units of °C/W or K/W, and is found by:

ΔT L

And convection in some natural convection applications where we have a confined air space heat transfer is actually where conduction not convection as designer may issue.

In some natural convection applications, which have I confined air space that is imagine you have an enclosure. And we assume that there are thermal setup inside the enclosure because they have mounted everything on a find heat sink, then your fins there and we accept the I mean we expect that they think keeps you know circulating and so on.

Which may or may not be the cause there is no place for circulation imagine both ends of the plate are blocked, or things are other ways confined one of the things you will notices that mostly maybe only conduction is available everything else is not available that is when people try to put a small circulator, a small fan inside the enclosure it ensure that you have convection this is what now, I would like to add saying to the purposes of my lecturing about is and they why I need you to pay attention to whatever I will say. Whenever we have this problem the designer may be thinking automatically natural convection takes place it may not take place that is where we probably need a small local circulator.

Now, these day's fans which are only 30 m m in a square are available, even if you tilt it and keep it and allow the local circulation you can start convection again and this we know about it. So, thermal conduction can occur only when a temperature refreshing axis metals are good conductors and so on and so on.

The identical mode of energy transfer occurs during electrical conduction, this is why most materials that are good thermal conductors are also good electrical conductors, primary exception to this is diamond, diamond has a thermal conductivity value five times higher than copper, but a dielectric strength ten times higher than rubber good know.

So, we have this issue diamond a still a diamond, diamond doesn't been called a diamond just for fun. In the physical world as I have written there is a very good exception to the observation of the other materials like basic metals and nonmetals saying the identical mode of energy transfer occurs during electrical conduction as in thermal. So, some very rare cases I do not know if it is still used at least when they this book is made which is based on experiences in the 90's and it has come out at about 2000, it was real they were things also which are mounted on diamond.

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2.2.1 Thermal Resistances

Often, the thermal resistances characterize the transmission of heat in the path of heat transfer. Examples of this include thermal pads, dielectric insulators, and adhesive bonding materials. Thermal resistance is most often expressed as temperature rise in units of °C/W or K/W, and is found by:

$$\theta_{cond} = \frac{\Delta T}{q_x} = \frac{L}{kA_c}$$

where A_c is the cross-sectional area available for conduction in units of m^2.

By comparing the thermal resistances, it sometimes becomes apparent which components in the heat transfer path are contributing most to the heat rise of the power component. Interestingly, we can describe convective heat transfer as a thermal resistance by

$$\theta_{conv} = \frac{\Delta T}{q_x} = \frac{1}{h_c A_s}$$

Thermal resistances characterized the transmission of it in the path of heat transfer is a expressed as rise and unit cell degrees centigrade and has found by this this we have covered earlier, it sometimes become a print which components or contributing to the heat rise of the interestingly power component they describe conductive heat transfer as a thermal resistance by this you have seen this know.

We have this thing here also we have something, by that is degree centigrade per watt here also degrees centigrade per watt and then you have here l by k a and then here you have the area which is used for affecting convection that is where I showed you the heat sink yesterday you have fins and on the fins there are grooves tiny grooves, they increase this surface area so surface is valley.

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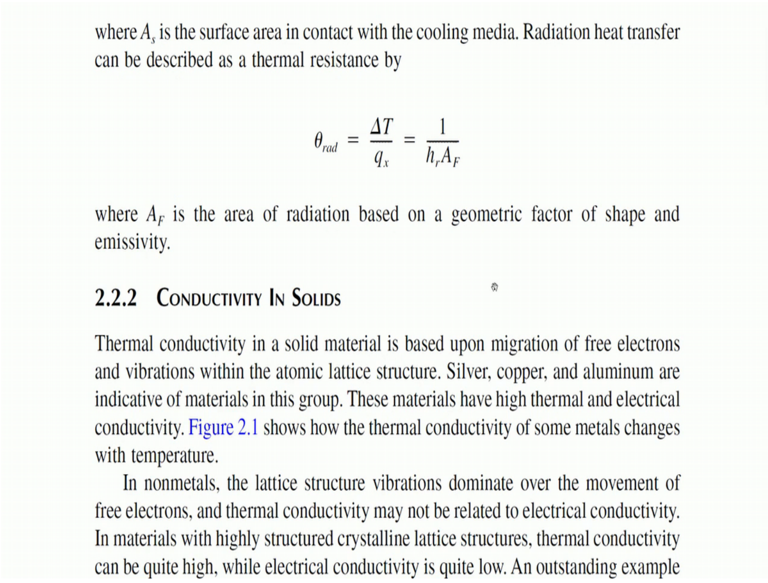

where A_s is the surface area in contact with the cooling media. Radiation heat transfer can be described as a thermal resistance by

$$\theta_{rad} = \frac{\Delta T}{q_x} = \frac{1}{h_r A_F}$$

where A_F is the area of radiation based on a geometric factor of shape and emissivity.

2.2.2 Conductivity In Solids

Thermal conductivity in a solid material is based upon migration of free electrons and vibrations within the atomic lattice structure. Silver, copper, and aluminum are indicative of materials in this group. These materials have high thermal and electrical conductivity. Figure 2.1 shows how the thermal conductivity of some metals changes with temperature.

In nonmetals, the lattice structure vibrations dominate over the movement of free electrons, and thermal conductivity may not be related to electrical conductivity. In materials with highly structured crystalline lattice structures, thermal conductivity can be quite high, while electrical conductivity is quite low. An outstanding example

Similar way by rearranging various parameters and simply find them, we also have in the case of radiation again same degree centigrade for what we have all the same. The amount of material which is I mean which was exposed, which I have shown you in the case of a practical heat sink, when we have deep fins the there is a shadow effect each fin will be forming a shadow in it.

So, only the things which are at the bottom of the heat sink will be seeing the outside the world. So, there certain practical examples, so we have something about the geometric factor of shape and so on.

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used in electronic cooling, thermal conductivity variances with pressure can be ignored. Temperature, however, can greatly affect the thermal conductivity of liquids or gases.

Within the range of temperatures used in electronic cooling, the thermal conductivity change of a gas is linear with temperature change but is different for each gas. The thermal conductivity change with temperature in liquids is not yet well understood. Figures 2.2 and 2.3 show the thermal conductivity change with temperature for selected gases and liquids, respectively.

2.3 CONDUCTION—STEADY STATE

2.3.1 CONDUCTION IN SIMPLE GEOMETRIES

In simple shapes such as a wall or cylinder, the heat flow is one-dimensional; that is, we require only a single coordinate to describe the spatial variation of the dependent variables.

Now, in simple shapes such as a wall or a cylinder the heat flow is one dimension that is a require only a single coordinate.

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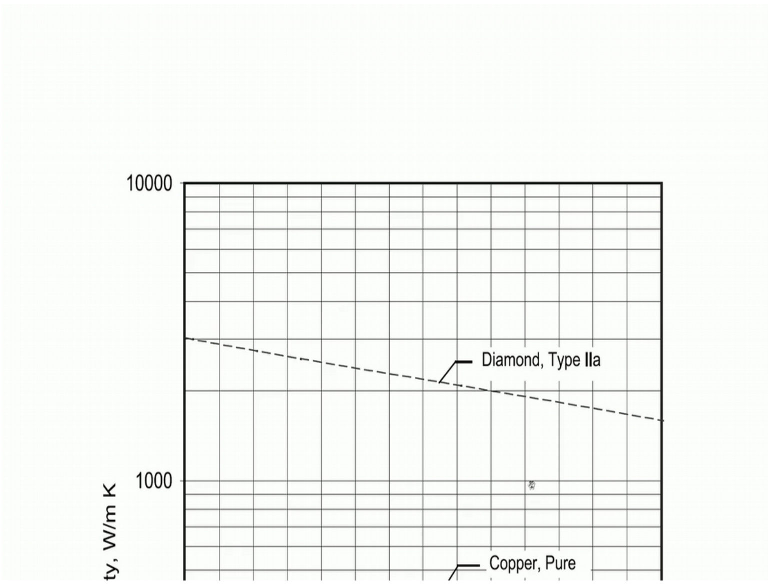

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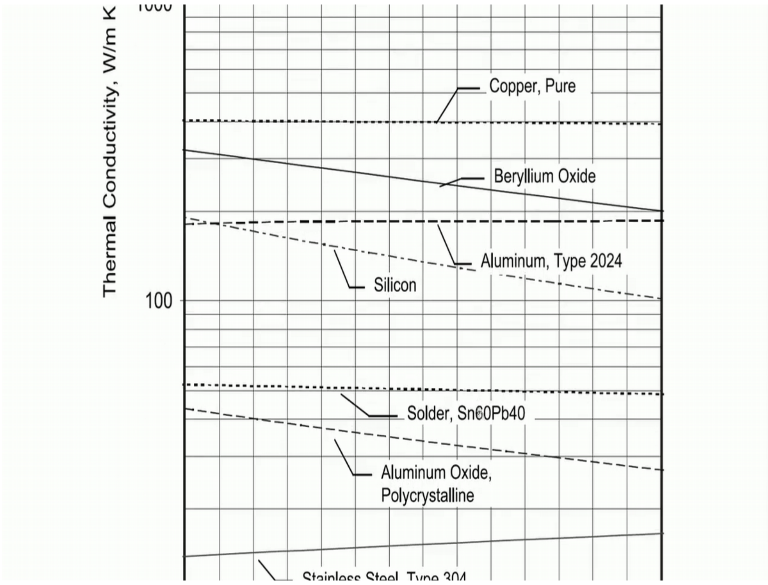

I think I skip this.

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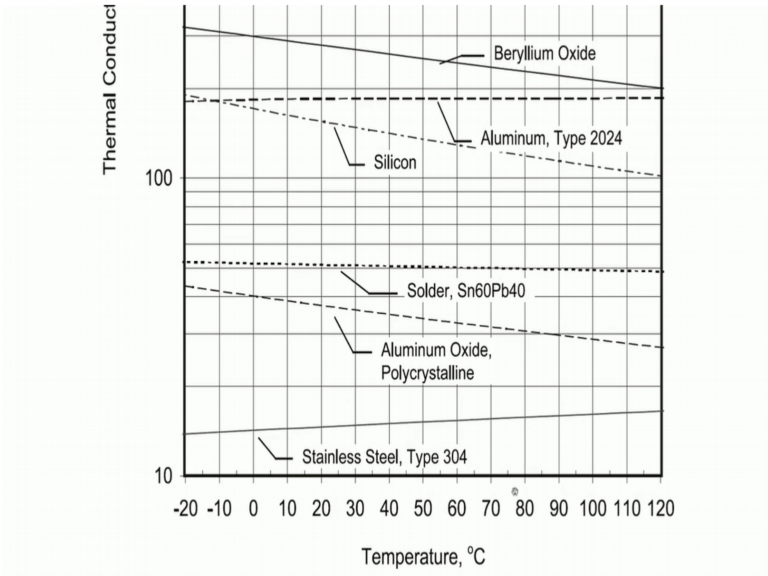

So, let me just check show you degree centigrade per watt in the case of I am sorry what plus degree centigrade diamond stairs there copper beryllium, silicon, and the bottom most know you have things like stainless steel meaning for a given heat, the amount of for a given amount of wattage amount of temperature rise is ridiculously high here, so, let me what you call go further.

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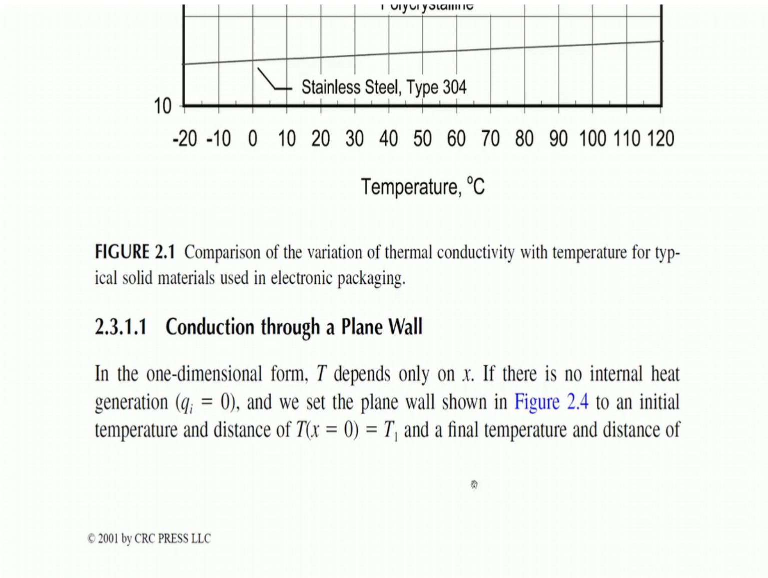

FIGURE 2.1 Comparison of the variation of thermal conductivity with temperature for typical solid materials used in electronic packaging.

2.3.1.1 Conduction through a Plane Wall

In the one-dimensional form, T depends only on x. If there is no internal heat generation ($q_i = 0$), and we set the plane wall shown in Figure 2.4 to an initial temperature and distance of $T(x = 0) = T_1$ and a final temperature and distance of

Now we come to these interesting things saying there are succeeding.

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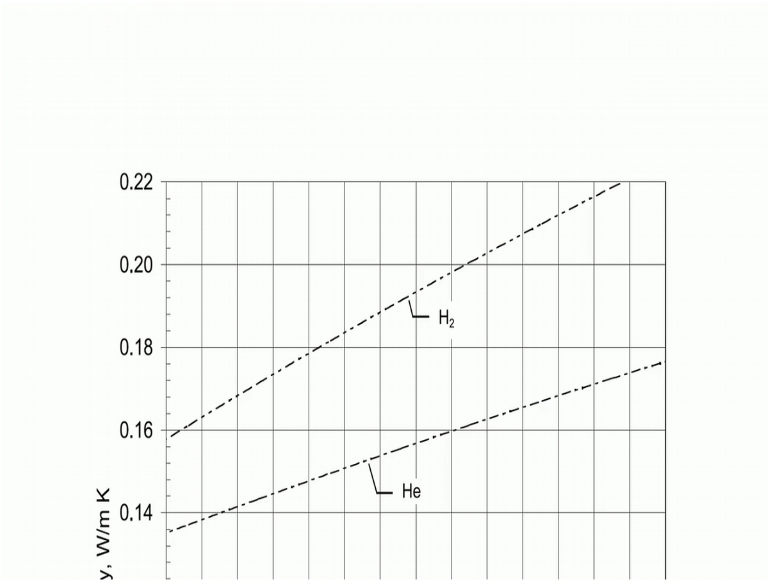

Chapters give you.

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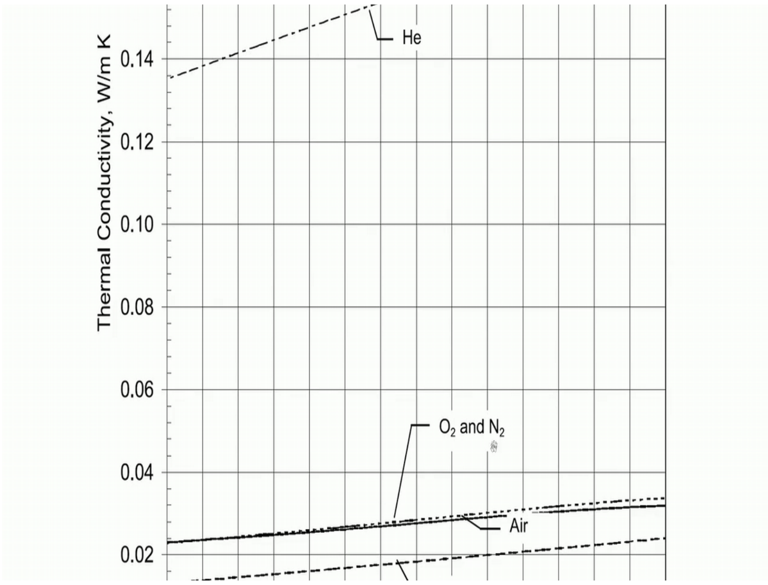

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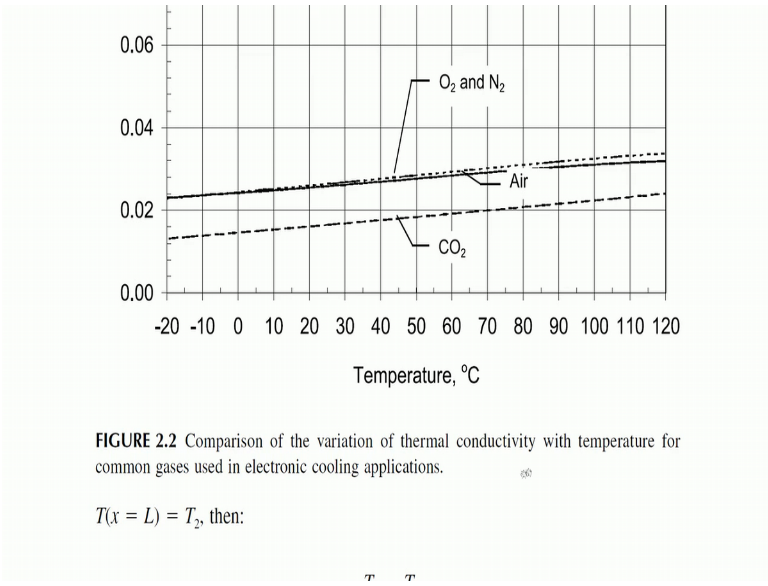

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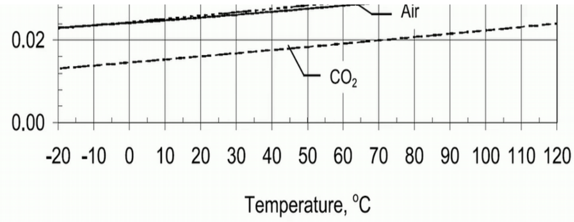

FIGURE 2.2 Comparison of the variation of thermal conductivity with temperature for common gases used in electronic cooling applications.

$T(x = L) = T_2$, then:

$$T(x) = \frac{T_2 - T_1}{L}x + T_1$$

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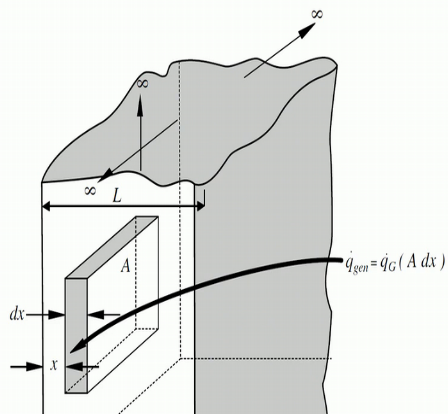

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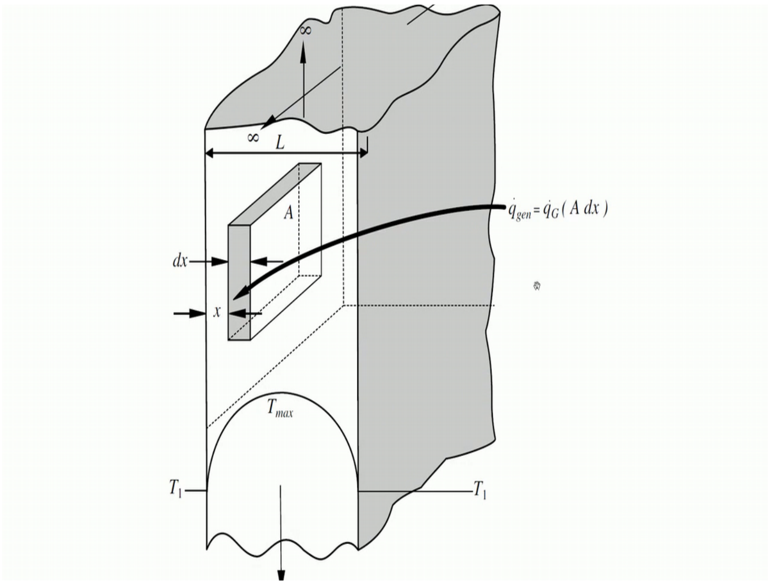

Things related to this analytical part of it saying, we have a area then we have how heat is conducted from here from there how this thing is taken out and I have shown you a practical example of a heat sink on which 84 to 20 packages mounted and the total this is typically you know the total area.

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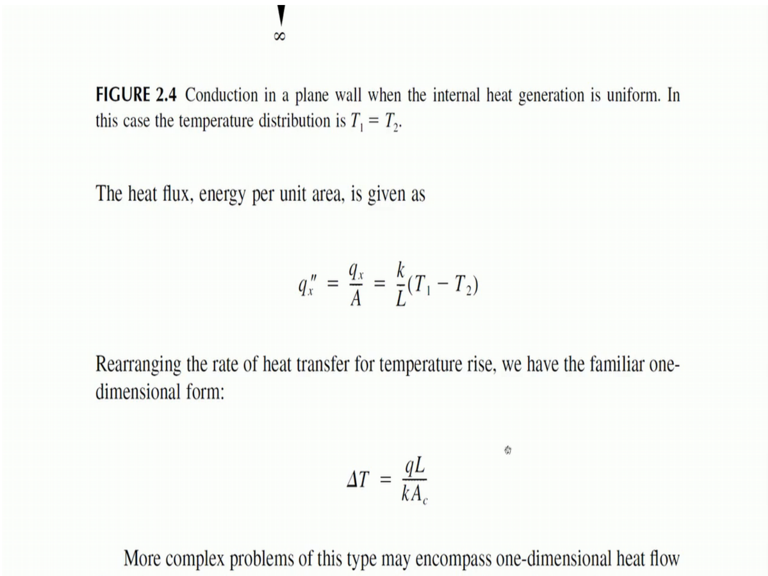

FIGURE 2.4 Conduction in a plane wall when the internal heat generation is uniform. In this case the temperature distribution is $T_1 = T_2$.

The heat flux, energy per unit area, is given as

$$q_x'' = \frac{q_x}{A} = \frac{k}{L}(T_1 - T_2)$$

Rearranging the rate of heat transfer for temperature rise, we have the familiar one-dimensional form:

$$\Delta T = \frac{qL}{kA_c}$$

More complex problems of this type may encompass one-dimensional heat flow

That is covered, when internal heat generation is uniform all this stuff know is given here rearranging the rate of heat transfer temperature rise we have.

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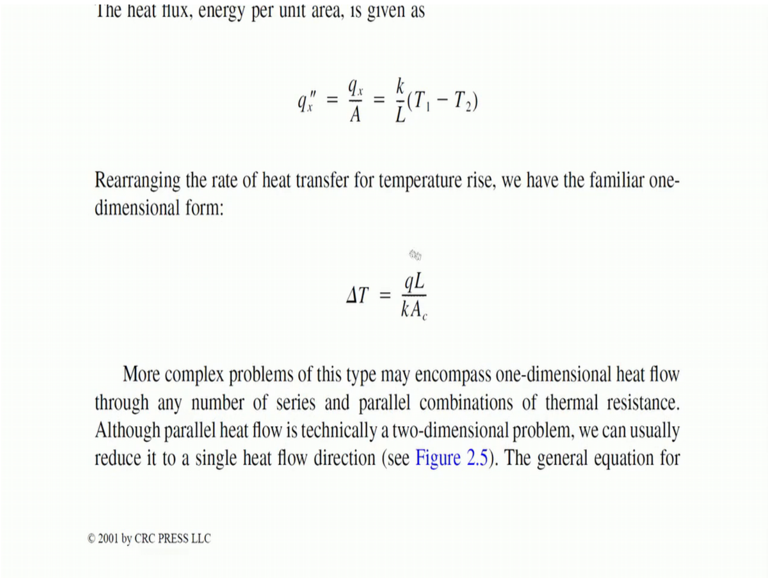

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$$\Delta T = \frac{qL}{kA_c}$$

More complex problems of this type may encompass one-dimensional heat flow through any number of series and parallel combinations of thermal resistance. Although parallel heat flow is technically a two-dimensional problem, we can usually reduce it to a single heat flow direction (see Figure 2.5). The general equation for

Everything has been reduced to a very convenient L by k into A, problems of this type may encompass one dimensional heat flow though any number of series and parallel combinations thermal resistance, parallel heat flow is technically a two dimensional problem we can reduce it to a single heat flow direction.

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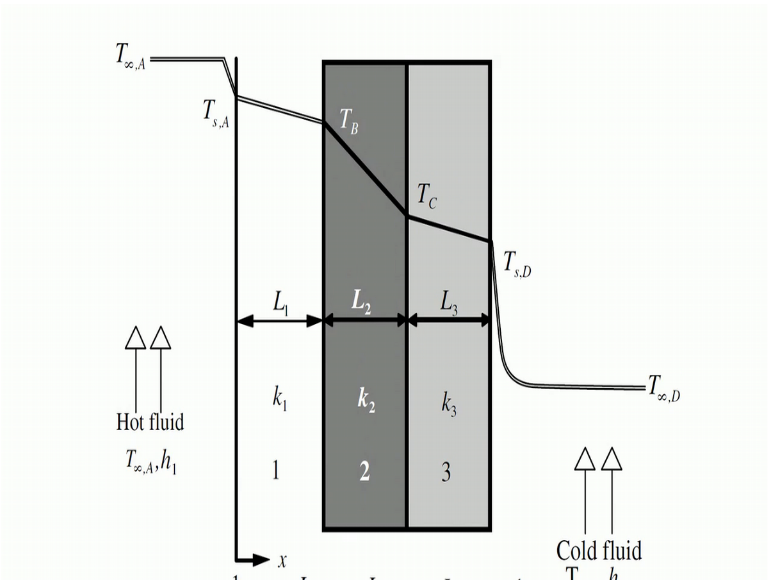

If we go to the this is what is often used in all the lectures in electronic cooling I said there are other lectures, everywhere you see here very important thing we need to consider here is you have seen a.

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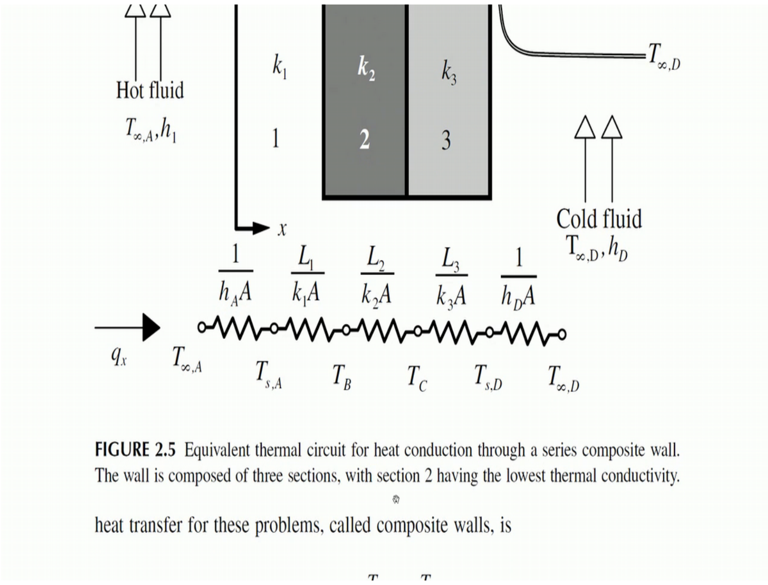

Beauty on one direction; we have a cold fluid, meaning it could be air and the other direction internal to whatever structure we have and this can represent the wall followed know.

One thing you notice is whenever there is conductivity i e amount of conductivity, we see that the temperature gradient is very, very high, but the moment you come to the convection here also you have it, but then you will notice here have a noticed this small the boundary layer seems to contribute tremendously, see here only all the effect takes place only in the small boundary layer area.

Why this picture is shown here is you have several case here you will see here 1 k, 1 k, 1 k, if we can somehow estimate these things depending on the difference in materials. So, one of them whenever there is a large temperature differential here it could mean it could be an insulating material some sort you understand know and if you reduce the length; obviously, we can avoid this thing and then this can start here the moment you have more and more length you will have.

So, many of these difficulties lot of what you call temperature rise and so on, the other material could be your actual conductive material. So, the temperature gradient in a highly conductive material will be small in a insulating material it will be high.

So, if you adjust these parameters in the end all you need to do is somehow you have seen here it is explained here the wall is composed of three sections. Section two having the lowest thermal conductivity, section two, section three is higher conductivity again here know we probably have some you know material, which is the wall itself and then these are insulators and so on.

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heat transfer for these problems, called composite walls, is

$$q_x = \frac{T_{\infty,1} - T_{\infty,N}}{\sum \theta_t}$$

Therefore, we can describe a composite wall with three materials (*A*, *B*, and *C*) in series and convective heat transfer along the face of material *A* and *C* as

$$q_x = \frac{T_{\infty,1} - T_{\infty,4}}{\left[\left(\frac{1}{h_{c,1}A}\right) + \left(\frac{L_A}{k_A A}\right) + \left(\frac{L_B}{k_B A}\right) + \left(\frac{L_C}{k_C A}\right) + \left(\frac{1}{h_{c,4}A}\right)\right]}$$

The overall heat transfer coefficient, *U*, is sometimes used, which we describe as

$$U \equiv \frac{q}{A \Delta T}$$

So if you go on to the heat transfer all these problems called composite walls you see here infinity and so on. So, on and all that know by sigma it is nothing, but three materials A, B, C in series and convective heat transfer along the face of the material, A and C except the thing, can whole thing nicely we can make it into the usual resistive equation, you remember that you know how to calculate equivalent resistance r 1 plus r 2.

So, I know you have some where r 1 plus r 2 divided by the other things you can I think subsequent lectures the whole thing is clarified. So, all the heat transfer coefficients can be added, the advantages of these a resistors circuit like this says all the resistance can be added easily just as you would do the resistance 1, 2, 3 then you have a temperature difference. And in the end we have a beautiful thing we have overall heat transfer coefficient which given a amount of per and you have given a amount of area we directly you can compute the effective circuit.

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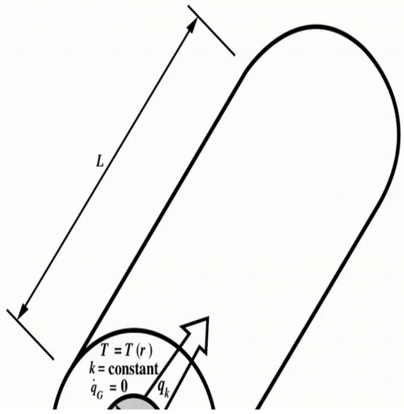

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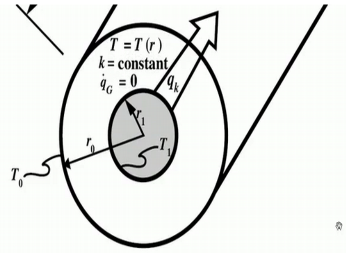

FIGURE 2.6 Radial heat conduction through a cylindrical shell having no internal heat generation.

Using the overall heat transfer coefficient, the previous expression for the composite wall of Figure 2.5 becomes

$$U = \frac{1}{\theta_{tot}A} = \frac{1}{\left[\left(\frac{1}{h_{c,1}}\right) + \left(\frac{L_A}{k_A}\right) + \left(\frac{L_B}{k_B}\right) + \left(\frac{L_C}{k_C}\right) + \left(\frac{1}{h_{c,4}}\right)\right]}$$

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$$U = \frac{1}{\theta_{tot}A} = \frac{1}{\left[\left(\frac{1}{h_{c,1}}\right) + \left(\frac{L_A}{k_A}\right) + \left(\frac{L_B}{k_B}\right) + \left(\frac{L_C}{k_C}\right) + \left(\frac{1}{h_{c,4}}\right)\right]}$$

2.3.1.2 Conduction through Cylinders and Spheres

In electronic cooling, the most prevalent case of radial heat transfer is the tube containing a flowing coolant. Here, heat flows from the outer surface of the tube to the center of the tube (see Figure 2.6). The rate of heat transfer in the radial direction of the tube is

$$q_k = -kA\frac{dT}{dr} = -k(2\pi rL)\frac{C_1}{r} = 2\pi Lk\frac{T_o - T_i}{\ln\left(\frac{r_o}{r_i}\right)}$$

Note that this shows that the distribution of the heat flow is logarithmic, not linear

You have seen this know, this is what a commercial heat sink manufacturers will be giving this what I have spoken to also earlier in my earlier lectures I have told you somebody has done the work for you. More than I will put it the other ways somebody has evaluated these things I have catalogue it in, standard conditions understand know you are equipment may not have the identical standard conditions which they have examined these things.

So, I have given you an extreme example of a fan or a blower, in the description they say this can take static pressure or it can check pressure of one inch and then flow of 20 c f m. Intuitively we think that total is valid it is a lot like a switch, when you have a current we expect the voltage to be 0, same thing happens in the case of a fan static pressure very rarely we encompass and usually the rise know after the flow starts the turbulence and all is taken care of and the flow increases, after that it follows a nice path after a little while the moment you reached the open it is free you understand know the moment you have no resistance at all.

So, subsequently when we come to the blowers you can understand the characteristic if only one combination of back pressure, and flow it is optimum right now we are talking about the total amount of flow that can be got from the system. In reality we have one more unfortunate factor that is the electrical efficiency of the whole device. So, this is where the complications come. So, it is not just as if you then I have shown you what is called a 160 h d heat sink, and then we told you in extreme examples they will put one fan here and another fan here a 150 m m or 150 m m fan on both sides. So, the heat is taken across these are to be observed.

Now, get me let me get back overall heat transfer coefficient in the previous expression is you have this which I have shown, not withstanding all this the it is very much possible for using in the case of a radial tube, you see here you have seen this know if you know the various types of the physical parameters and you know the actually conductivity of this solid its. So, very much possible for us to do the necessary in the what you call the necessary mathematical expression, and try to get into absolute value rate of heat transfer in the radial direction of the tube which is given here.

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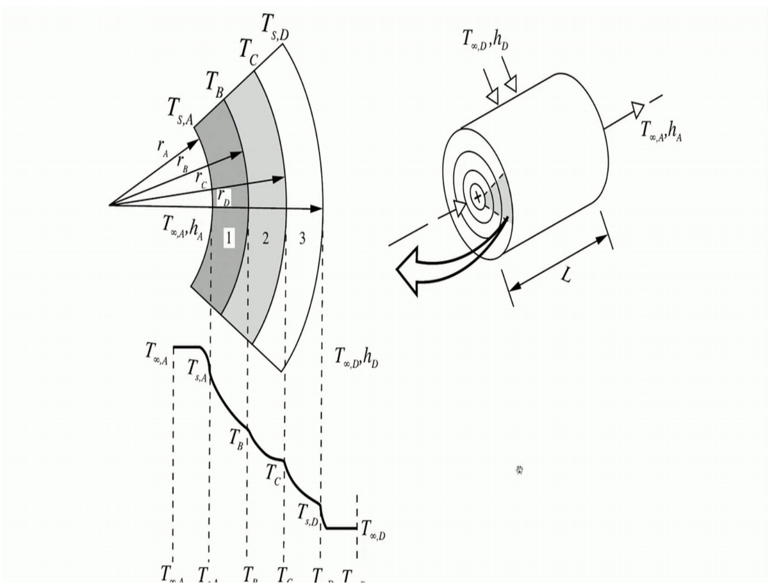

And this is what you are likely to find in all the textbooks.

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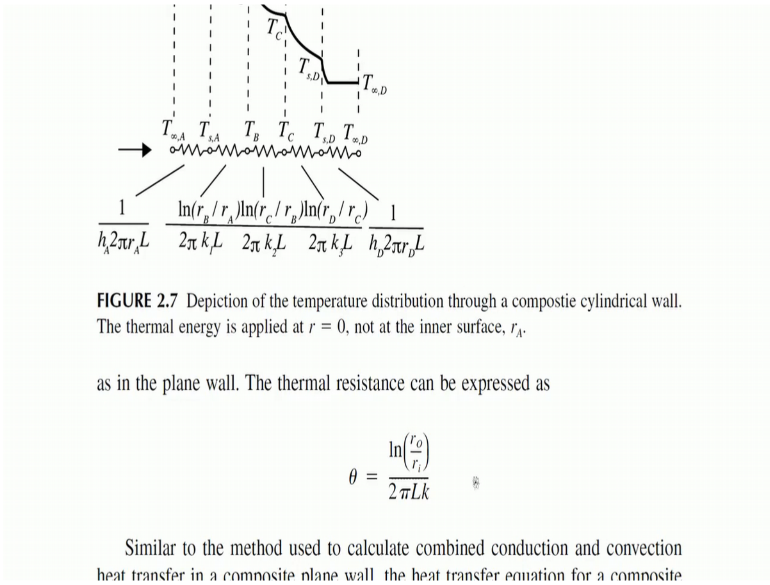

FIGURE 2.7 Depiction of the temperature distribution through a compostie cylindrical wall. The thermal energy is applied at $r = 0$, not at the inner surface, r_A.

as in the plane wall. The thermal resistance can be expressed as

$$\theta = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi L k}$$

Similar to the method used to calculate combined conduction and convection heat transfer in a composite plane wall, the heat transfer equation for a composite

You have seen here very, very important thing is as you go across the wall the more and more surface area is exposed. So, if something is steep; that means, less what you call conduction is taking place something is a little leveled out; that means, the conduction is getting better at every interface know you see this beautiful thing you have, where do such things occur anywhere you could do fully having a cylindrical capacitor or you could be having a core, a magnetic or otherwise, what you call something.

Which also tends to get hot that is where these relationships help, and combination of one phase being heated and as it goes how will the fins especially circular fins, how will they radiate I am sorry they exchange heat to the ambient can now be happily modeled you have seen here.

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as in the plane wall. The thermal resistance can be expressed as

$$\theta = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi L k}$$

Similar to the method used to calculate combined conduction and convection heat transfer in a composite plane wall, the heat transfer equation for a composite tube (see Figure 2.7) containing three materials and a flowing fluid is

$$q = \frac{\Delta T}{\sum_1^4 \theta} = \frac{T_{\infty,1} - T_{\infty,4}}{\frac{1}{h_{c1} 2\pi r_1 L} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_A L} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi k_B L} + \frac{\ln\left(\frac{r_4}{r_3}\right)}{2\pi k_C L} + \frac{1}{h_{c4} 2\pi r_4 L}}$$

Using the overall heat transfer coefficient, the previous expression for the composite

So, you have here beautiful integrated or submitted values you see the summation will take us here unless you take a work bit example and do it for yourself. It may not make sense, and for me it makes sense only when I need to explain to you that it is very much possible to accurately determine these things only thing, we do not know is often this k is not very well known well, very well defined because sometimes occasionally k is also depend on dependent on temperature itself, and a lot of it about the fabrication process in certain fabrication processes the materials are compacted, typically best example is forging if something is forged the conductivity will be high.

And if something is what you call made by some other thing normal especially, if it is gravity die caster gravity mold the there always microscopic voids inside, and that will not have the same k though it is aluminum the one what we have done in by gravity die casting, and the sand molds will be very poor compared to something which is pressured die cast.

So, if you see all your motorbike what you call engines and oil invariably all the items are pressure die cast. So, the conductivity is very, very high in contrast to your experimental things what you have like to do, in case if you have seen my earlier enclosure design lectures you does I have shown you a video on a water cooled power electronics module, which we are making if I get a chance and if it is ready I will show you a picture as you mill it. And if you come close to it you can see that there are small voids this is where this k in your very varies, so experimentally you need to find out.

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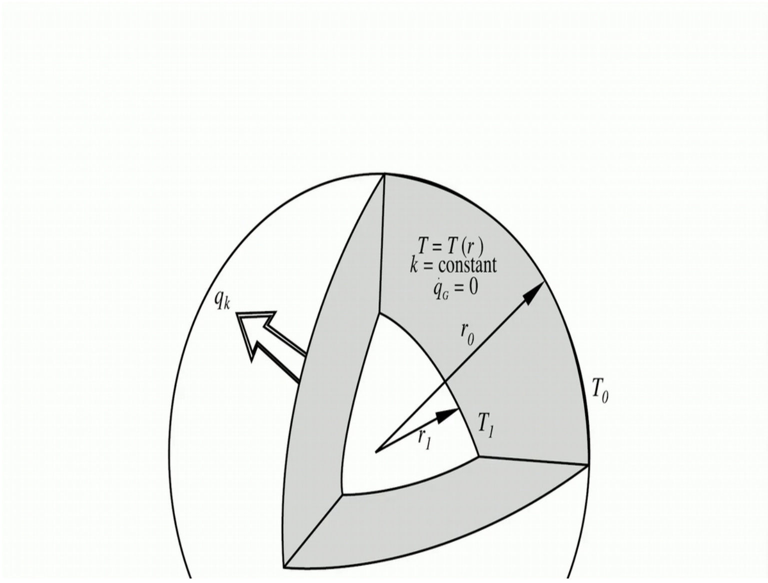

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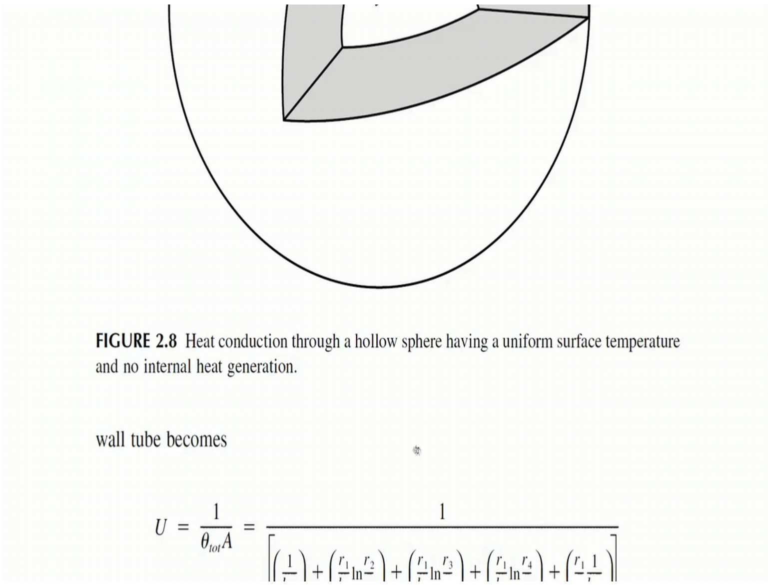

Let us say beauty, so we have this all this beautiful heat conduction through a hollow sphere and we uniform surface temperature and are known internal heat generation. So, I do not know where we can think about except maybe some shield, which is a used and top of it I will avoid use the word of making a bomb, but probably there is enough heat generation.

So, even ideal conditions like this spherical actually more rare than spherical usually hemispherical the condition can be easily be calculated and these expressions are used directly in computer packages where if you specify the various things the problem is broken down into manageable things like this.

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$$U = \frac{1}{\theta_{tot}A} = \frac{1}{\left[\left(\frac{1}{h_{c1}}\right) + \left(\frac{r_1}{k_A}\ln\frac{r_2}{r_1}\right) + \left(\frac{r_1}{k_B}\ln\frac{r_3}{r_2}\right) + \left(\frac{r_1}{k_C}\ln\frac{r_4}{r_3}\right) + \left(\frac{r_1}{r_4}\frac{1}{h_{c4}}\right)\right]}$$

We can simplify the equation for heat conduction in spherical coordinates to

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right) = \frac{1}{r}\frac{d^2(rT)}{dr^2} = 0$$

If T_i is the temperature at r_i and T_o is the temperature at r_o, then the temperature distribution in the sphere (see Figure 2.8) is

$$T(r) - T_i = (T_o - T_i)\frac{r_o}{r_o - r_i}\left(1 - \frac{r_i}{r}\right)$$

You have seen this beautiful thing temperature and so on and so on, we have nice expressions can be evaluated and if you are a person who's can write code or about to right code better you read it, so you can always be happy that all possible combinations.

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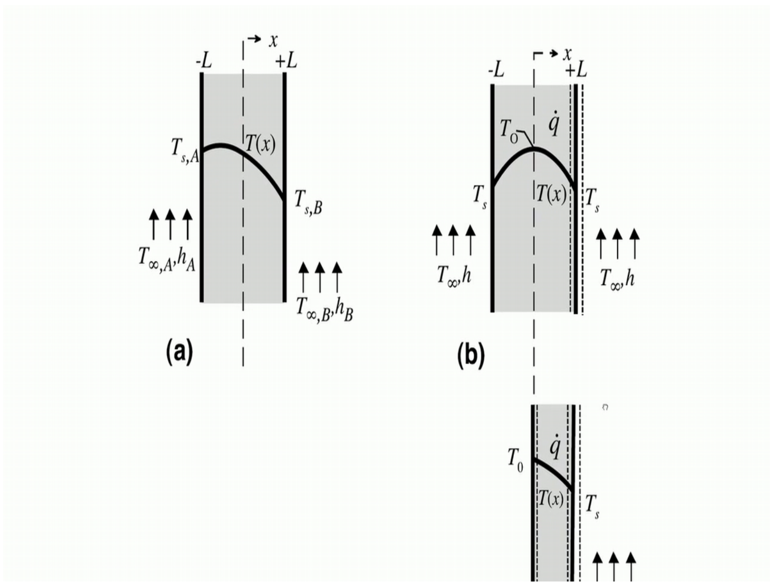

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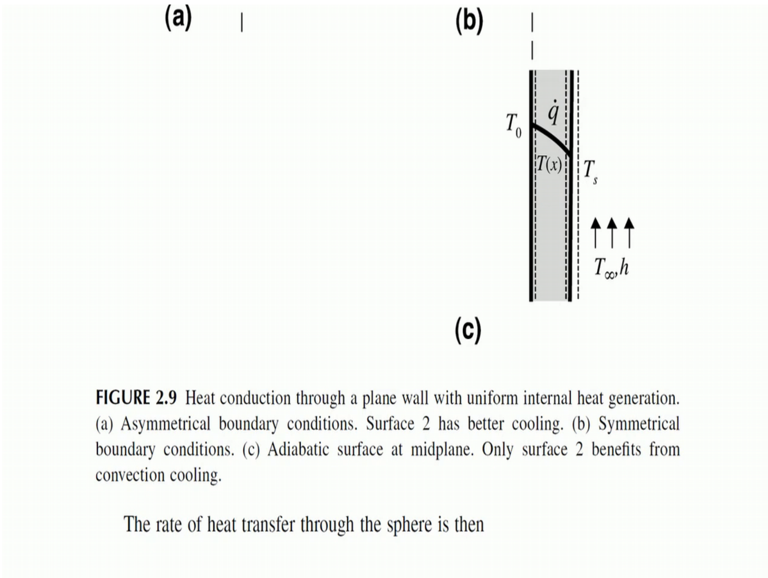

FIGURE 2.9 Heat conduction through a plane wall with uniform internal heat generation. (a) Asymmetrical boundary conditions. Surface 2 has better cooling. (b) Symmetrical boundary conditions. (c) Adiabatic surface at midplane. Only surface 2 benefits from convection cooling.

The rate of heat transfer through the sphere is then

You see here there are beautiful combinations of type a asymmetrical boundary conditions means, one side temperature is different from the other side. Symmetrical boundary conditions meaning you have both sides, what you call you have seen this h A, h B heat transfer equation on side A and B, and it gets both have similar things and you have a what you call temperature of the surface.

So, typically a fin know may be able to you know behave like this and finally, the if something is closer on one surface the other surface the here know you have this by convective heat transfer things can be open, this is typically the case with an enclosure which is trying to transfer heat across. So, you may wondering how do ever the able to make yes even if you see you're, the power supply unit which comes with your laptop the whole thing is a some plastic enclosure.

So, I am sure you will have some burnt out for supplies, next time open the top cover and see most of the surface inside know is probably one more metallic thing, occasionally aluminum and it close in contact with the outside cover. The whom you keep it close in contact and then you also reduce the thickness of the plastic enclosure, you have beautiful conduction across both the surfaces and an amount of cooling is possible, the second part is where know your creativity is required like that after you understand the rate at which things cool and all that it is very much possible for you.