Electronics Enclosures Thermal Issues

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Lecture – 13

Schonholzer moduls

Hello, can you switch on the monitor; I am not able to see the monitor in the front this monitor is not here. So, I am not able to see my face, you can start recording like the monitor work on its own monitor is not on; this and that is record.

Yes sir.

Ah right no problem power is there? It has started somebody may have switched off the

It has started sir.

I can start.

You can start.

Ok I think we can remove the other thing right.

Hello allow me to start and recapitulate a little of what I have taken from Remsburg's PDF notes. As I said he is somebody was worked you know widespread let me I am sorry for you know mentioning it , but the treatment is both very very thorough; meaning for every what you call several standard conditions including combinations of various geometries, analytical solutions have been formulated. .

And they are useful in case you want to write code or you know use it in a one of instance as in the case of aerospace applications. In the case of aerospace at least in aero some minimum quantities are there may be the quantities run into a few 100's including replacement spares.

So, you can I have given you a instance of where you have a box used by aircraft people, where the sides have fins like this is a box and this is a fins. And then you insert the PCBs inside and ensure that they make contact with the outside. So, you have see there two things are there one is the contact interface, which is real; then second thing is main thing is by conduction.

And you have a control on the pressure and you can do whatever you would like to do. So, these so, called PCB card guide printed circuit card guide or any module which has contact can deal with it effectively. And I am saying even if there is a small batch of maybe 200 or 300 aircraft, this stock of spare such that know it can be maintained for 20 or 30 years .

Say large number is involved in that case it makes sense to experiment, find out, optimize and make your design. Coming back to the other applications for example, if you are in armaments, you have made some something which goes and I will use the word self destruct and self distracting someone else..

Once it is deployed it is lost there is nothing like you are bringing it back and repairing it. And if you follow the news channels you know not all launches are successful either armament or other way and extreme is probably space. While in principle, you can go out and repair a spacecraft; it is not that easy things like normal communication satellites.

And then a good example for us is the GPS system in orbit, they are expected to stay there for a very long time. And the conditions are different understood know; there we have extreme radiation, not much of a chance for a medium outside to exchange the heat; like external surface does not have convection and even internal surface you cannot afford to have much of a what you call gaseous medium .

I leave it at that point the only thing is all those formulations which have been given earlier by analytical methods are required in such extreme conditions; however, for the normal what you call usage and things still things are required. I am wearing which is what is now fashionable some of you must have seen is activate a trackers, which have become know extremely fashionable.

It monitors I am know I do not know what are it monitors and whom all it keeps a tab on how lazy I am. And then if you see inside other than the normal band and this; this the guaranteed that it is essentially waterproof.

So, it is with the earlier watches and there are even mobiles, which are waterproof. And front a scratch proof and everything whenever they say proof know you can know it is particular thing is that like that end. So, at the back we have this back rare surface has a tendency to get hot. So, various methods are used; so, what the designers do you can now look at.

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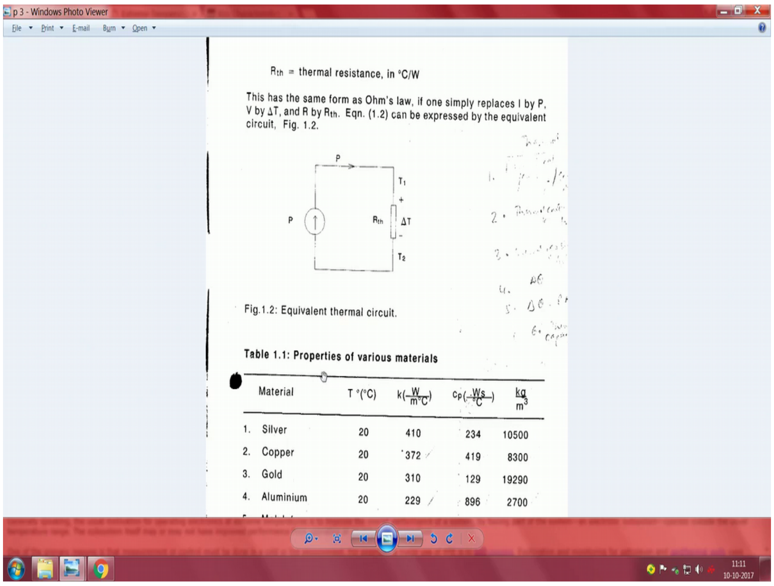

R_{th} = thermal resistance, in °C/W

This has the same form as Ohm's law, if one simply replaces I by P, V by ΔT, and R by R_{th}. Eqn. (1.2) can be expressed by the equivalent circuit, Fig. 1.2.

Fig.1.2: Equivalent thermal circuit.

Table 1.1: Properties of various materials

	Material	T °(°C)	$k(\frac{W}{m°C})$	$c_p(\frac{Ws}{°C})$	$\frac{kg}{m^3}$
1.	Silver	20	410	234	10500
2.	Copper	20	372	419	8300
3.	Gold	20	310	129	19290
4.	Aluminium	20	229	896	2700

My screen this is taken from another source as I said now, one professor Schonholzer has come and worked with us. I have shown earlier, but I will get back to you again so, that much easier way solving all this is somehow get yourself into a equivalent thermal resistance. At the starting point, the thermal resistance is very much valid because normal laws of a computing a network can easily be done.

Now, it comes to other thing basically here there is no heat buildup or storage. So, two things which are very very useful for us is probably this a simple resistor and then I think you have already by now know you have gone those thing.

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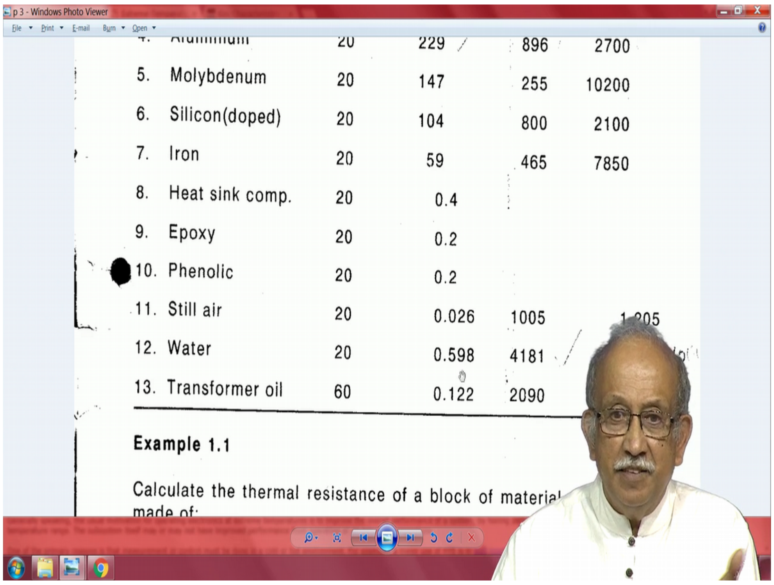

4.	Aluminium	20	229	896	2700
5.	Molybdenum	20	147	255	10200
6.	Silicon(doped)	20	104	800	2100
7.	Iron	20	59	465	7850
8.	Heat sink comp.	20	0.4		
9.	Epoxy	20	0.2		
10.	Phenolic	20	0.2		
11.	Still air	20	0.026	1005	1.205
12.	Water	20	0.598	4181	
13.	Transformer oil	60	0.122	2090	

Example 1.1

Calculate the thermal resistance of a block of material made of:

And then at down this word yesterday refer to and I try to get back to you. Aluminum has this beautiful nice number of watts per you know what you call meter degree centigrade of 229; as you go down our phenolic and epoxy board that is the GESE board we have has very poor conductivity; nearly you know 1000 times lower .

Further if you do, if you go for still air it is 10000 times lower and water is I mean slightly better maybe 500 times. And then even transformer oil and all that know conductivity as 4.

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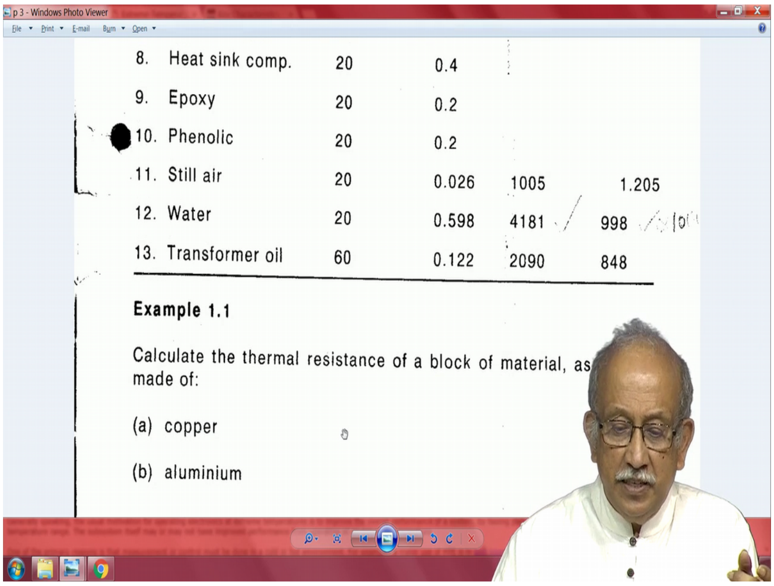

8.	Heat sink comp.	20	0.4		
9.	Epoxy	20	0.2		
10.	Phenolic	20	0.2		
11.	Still air	20	0.026	1005	1.205
12.	Water	20	0.598	4181	998
13.	Transformer oil	60	0.122	2090	848

Example 1.1

Calculate the thermal resistance of a block of material, as made of:

(a) copper

(b) aluminium

So, a worked example here talks about the next picture talks about saying.

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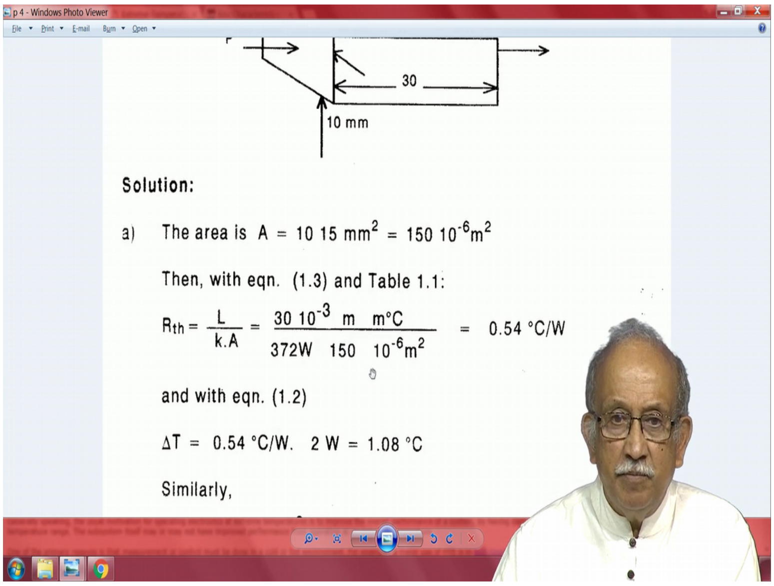

Solution:

a) The area is $A = 10\ 15\ mm^2 = 150\ 10^{-6} m^2$

Then, with eqn. (1.3) and Table 1.1:

$$R_{th} = \frac{L}{k.A} = \frac{30\ 10^{-3}\ m\ \ m°C}{372W\ \ 150\ \ 10^{-6} m^2} = 0.54\ °C/W$$

and with eqn. (1.2)

$$\Delta T = 0.54\ °C/W.\ \ 2\ W = 1.08\ °C$$

Similarly,

In case you have a block like this how does it behave? It is very very easy everything you know critically you know talks about this k of the material here you understood know you have seen this this k. So, for copper we have one number.

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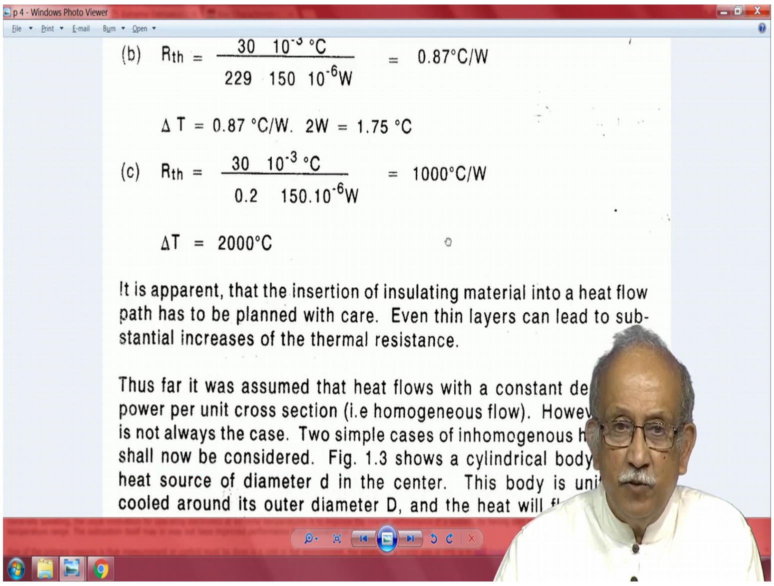

(b) $$R_{th} = \frac{30\ \ 10^{-3}\ °C}{229\ \ 150\ \ 10^{-6} W} = 0.87°C/W$$

$$\Delta T = 0.87\ °C/W.\ \ 2W = 1.75\ °C$$

(c) $$R_{th} = \frac{30\ \ 10^{-3}\ °C}{0.2\ \ \ 150.10^{-6} W} = 1000°C/W$$

$$\Delta T = 2000°C$$

It is apparent, that the insertion of insulating material into a heat flow path has to be planned with care. Even thin layers can lead to substantial increases of the thermal resistance.

Thus far it was assumed that heat flows with a constant de
power per unit cross section (i.e homogeneous flow). Howev
is not always the case. Two simple cases of inhomogenous h
shall now be considered. Fig. 1.3 shows a cylindrical body
heat source of diameter d in the center. This body is uni
cooled around its outer diameter D, and the heat will

And then for aluminum you see copper is 150 comes here and in the case of for aluminum; we have this 229. So, this itself know you know how things work and if you come down, we come to the this what you call very low figure which will gives you a very high thermal you know conductivity .

So, I have a thermal resistance which is 1000 degree centigrade per watt.

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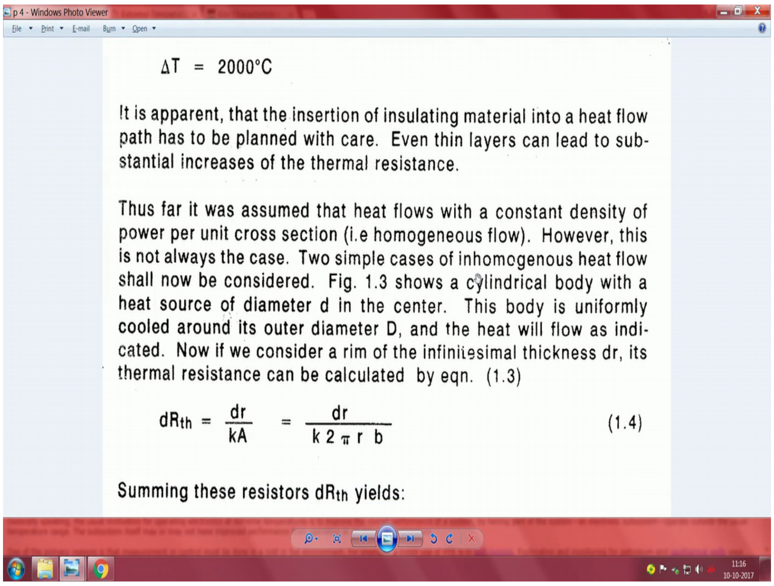

$$\Delta T = 2000°C$$

It is apparent, that the insertion of insulating material into a heat flow path has to be planned with care. Even thin layers can lead to substantial increases of the thermal resistance.

Thus far it was assumed that heat flows with a constant density of power per unit cross section (i.e homogeneous flow). However, this is not always the case. Two simple cases of inhomogenous heat flow shall now be considered. Fig. 1.3 shows a cylindrical body with a heat source of diameter d in the center. This body is uniformly cooled around its outer diameter D, and the heat will flow as indicated. Now if we consider a rim of the infinitesimal thickness dr, its thermal resistance can be calculated by eqn. (1.3)

$$dR_{th} = \frac{dr}{kA} = \frac{dr}{k\,2\,\pi\,r\,b} \qquad (1.4)$$

Summing these resistors dR_{th} yields:

Insertion of any insulation material into heat flow path as we planned with care; even thin layers can lead to substantial increases of thermal resistance. Now if you can relate what I showed you yesterday, you will see that the contact interface and the amount of pressure you apply across it seemed to have a marked effect in it.

So, in the other correlations which it is given in the what you call the references at the back something called asperity angle has been mentioned; saying of something can be approximated a small dome like thing; by pressure it will come down . Especially one of the materials is very soft, the other is relatively little harder as you squeeze them the pressure seems to increase the contact area; the moment you increase the contact area you have you know this a will go up and moment the area goes up thermal resistance come down comes down; you see here now.

Thermal resistance comes down and so on and so, on so, on like that. So, we have a long list was you know mentioned there yesterday if you remember saying what all seems to have a difference in that big list. Temperature seems to have second order effect not immediately the external temperature does not seem to have a more threatening thing ah;

I mean the other factors seem to have a more threatening thing than the simple temperature. And in our; this is class notes prepared for our master students you will see that same relations have been made here.

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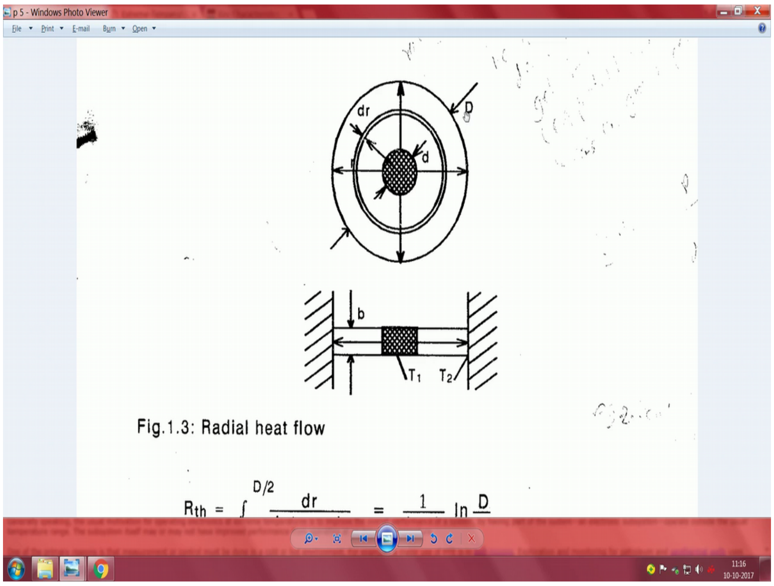

Fig.1.3: Radial heat flow

$$R_{th} = \int^{D/2} \frac{dr}{\quad} = \frac{1}{\quad} \ln \frac{D}{\quad}$$

Saying in case there is a radial thing as in; you have a circular disc you understood know; this is circular disc . And then this is the outside and there is an external you know what you call outer diameter in the diameter and all that.

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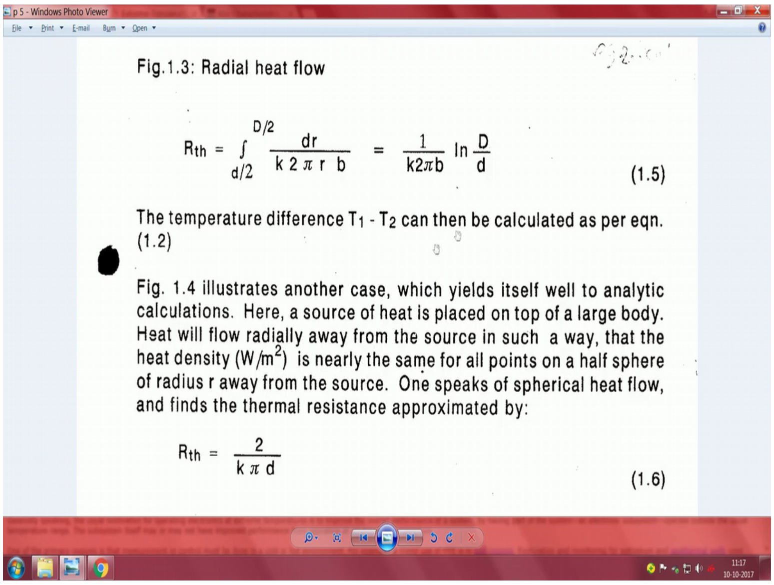

Fig.1.3: Radial heat flow

$$R_{th} = \int_{d/2}^{D/2} \frac{dr}{k\,2\,\pi\,r\,b} = \frac{1}{k2\pi b} \ln \frac{D}{d} \qquad (1.5)$$

The temperature difference $T_1 - T_2$ can then be calculated as per eqn. (1.2)

Fig. 1.4 illustrates another case, which yields itself well to analytic calculations. Here, a source of heat is placed on top of a large body. Heat will flow radially away from the source in such a way, that the heat density (W/m^2) is nearly the same for all points on a half sphere of radius r away from the source. One speaks of spherical heat flow, and finds the thermal resistance approximated by:

$$R_{th} = \frac{2}{k\,\pi\,d} \qquad (1.6)$$

Where in the case of a radial heat flow how things happen. And I have already shown you radial heat flow does not mean it needs just necessarily circular; many infinitely large thing as in a heat sink which I showed you that hd 160 meant for high density .

If you have a stud mounted diode in the middle understand no stud mounted diode you turn the stud and then it clamps itself , you will end up with this sort of material which in the near area depending on the temperature difference and all that; within I expect within around 80 to 100 millimeters; the thing is essentially radial,

And then, their graphical methods to compute how the isothermals are made and so, on. And then of course, these are all for radial heat flow as per I mean simplified equations.

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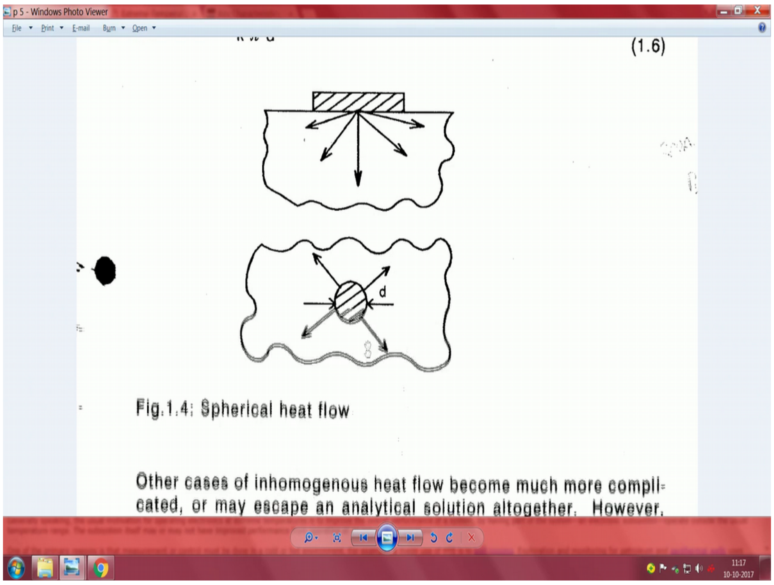

(1.6)

Fig.1.4: Spherical heat flow

Other cases of inhomogenous heat flow become much more complicated, or may escape an analytical solution altogether. However,

Similarly in the case of a spherical heat flow; if you have a small point source; approximated point source more than point source it is a small disc like thing in the cases spherical heat flow.

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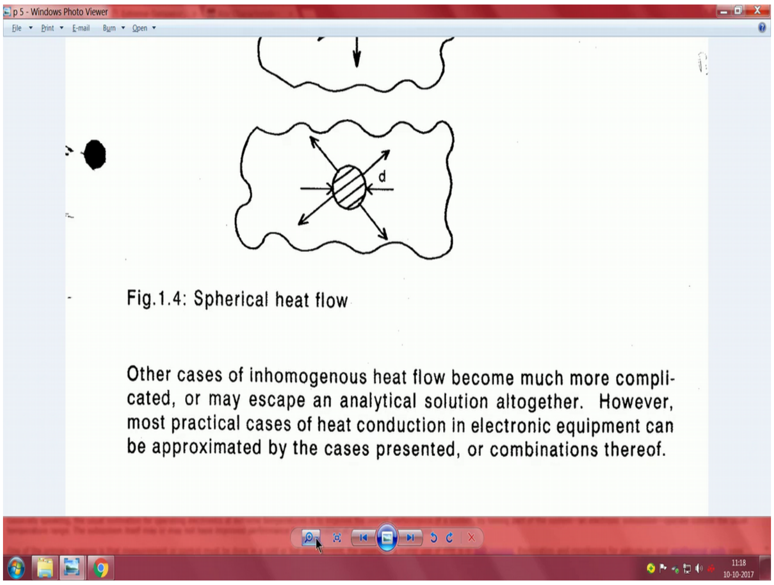

Fig.1.4: Spherical heat flow

Other cases of inhomogenous heat flow become much more complicated, or may escape an analytical solution altogether. However, most practical cases of heat conduction in electronic equipment can be approximated by the cases presented, or combinations thereof.

Now, see what has been written in there it is just maybe please; I mean be kind to me and the person has written. In case you are a professional, you are most compact I mean most welcome to add to this; much more complicated; may escape analytical solution. Most practical applications; so, heat conditional electronic equipment can be approximated by formulas which are presented there.

Now, we come to a small explanation.

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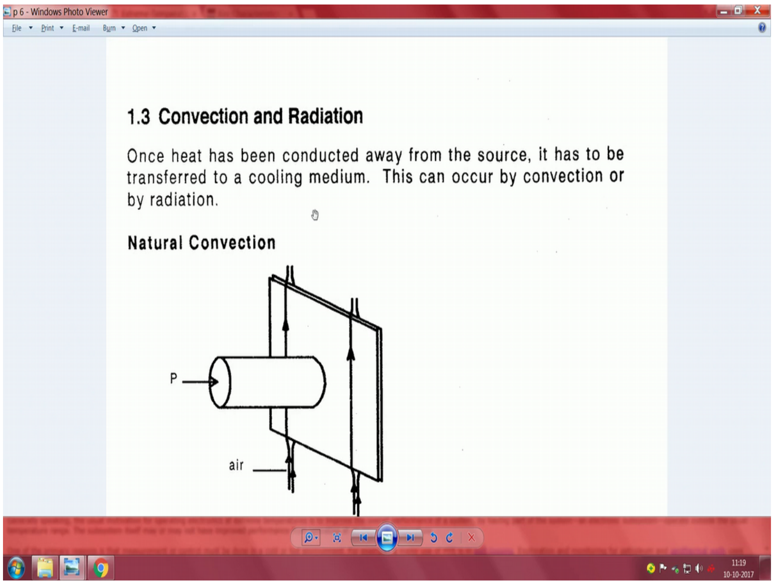

1.3 Convection and Radiation

Once heat has been conducted away from the source, it has to be transferred to a cooling medium. This can occur by convection or by radiation.

Natural Convection

Why I avoided you know again writing down a board or anything is this being the video source, you can always come back go backwards in time and try to read what is being written here. And if my accent is a little tough to get along with, you can always hit the mute button. Once heat has been conducted away from the source, it has to be transferred to a cooling medium; this can occur by convection or by radiation.

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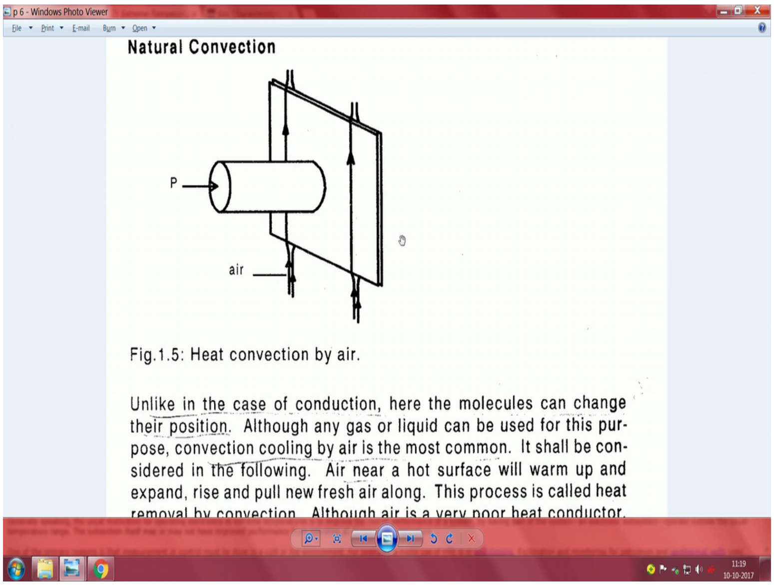

Natural Convection

Fig.1.5: Heat convection by air.

Unlike in the case of conduction, here the molecules can change their position. Although any gas or liquid can be used for this purpose, convection cooling by air is the most common. It shall be considered in the following. Air near a hot surface will warm up and expand, rise and pull new fresh air along. This process is called heat removal by convection. Although air is a very poor heat conductor,

In the case of natural convection you have seen this; this P is a slug which is fitted to a flat plate. And the plate can be different orientations it’s possible for us to keep it in the vertical thing such that the medium can flow on both sides.

So, if you have something which is let us say typically commercial heat sinks; you have air that is the cooling medium, but imagine your in a other liquid has in the case of a underwater lighting used in lighting up a fountain ..

Or you may have swimming pool sensors then you have sensors which see biological oxygen demand; which are active sensors are in fact, left in critical places typically where pollution is suspected. In those cases, we have water which is ready to take care of the medium.

And extreme case likely let us have an agriculture sensor you can have widely varying medium; when things are dry probably end up with dry air which is a very good insulator. And when something gets wet, things are slightly different and then when them something gets water logged from the thermal point of view its convenient, but from the ceiling ip index of protection point of view, they are not good. See in one of the early lectures, I have shown you there we have buried some sensors for agricultural monitoring.

So, if you take any plant we all are familiar with modeling of a full crop; crop can be modeled easily. Similarly there is plant modeling; plant modeling is also possible now we come to what is called root activity. So, just near the ground just above the ground there are certain amount of activity, just below the ground certain activity.

And deep down our commercial food crops where you know you grow basic what you call yearly or you know very seasonal crops. Very little effect is there below maybe a meter down again my opinion, but you kindly I stand corrected you look it up about it. And the maximum amount seems to be from just about let us say 5 centimeters above down to about 30 centimeters.

In all these places, these devices are mounted and invariably if you have a device it needs some powering up. It is very very convenient if we just have only maybe something like a 3 wire communication by which you can get data as well as power on to these modules; which will end up with having some amount of heating and power conditioning at the bottom.

So, in those cases we end up with if you look at my presentation we end up with this convection unlike in the case of conduction.

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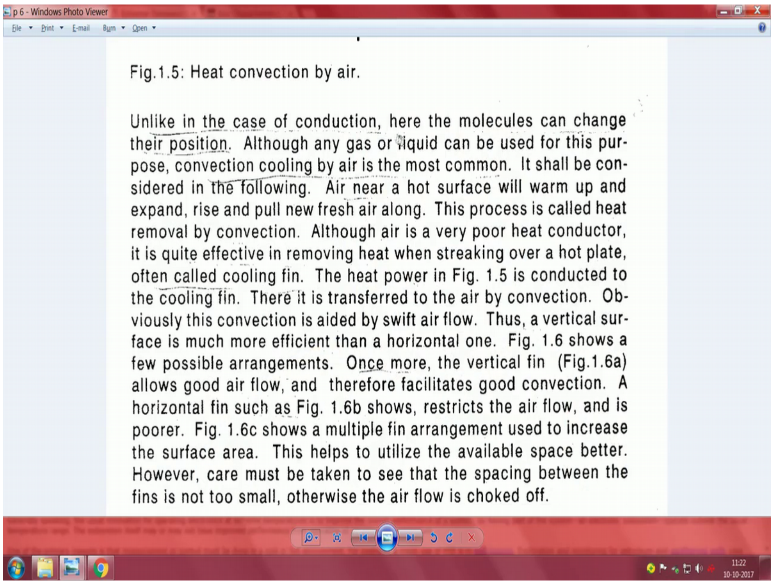

Fig.1.5: Heat convection by air.

Unlike in the case of conduction, here the molecules can change their position. Although any gas or liquid can be used for this purpose, convection cooling by air is the most common. It shall be considered in the following. Air near a hot surface will warm up and expand, rise and pull new fresh air along. This process is called heat removal by convection. Although air is a very poor heat conductor, it is quite effective in removing heat when streaking over a hot plate, often called cooling fin. The heat power in Fig. 1.5 is conducted to the cooling fin. There it is transferred to the air by convection. Obviously this convection is aided by swift air flow. Thus, a vertical surface is much more efficient than a horizontal one. Fig. 1.6 shows a few possible arrangements. Once more, the vertical fin (Fig.1.6a) allows good air flow, and therefore facilitates good convection. A horizontal fin such as Fig. 1.6b shows, restricts the air flow, and is poorer. Fig. 1.6c shows a multiple fin arrangement used to increase the surface area. This helps to utilize the available space better. However, care must be taken to see that the spacing between the fins is not too small, otherwise the air flow is choked off.

The model this positional change and so, on know convection by cooling is the most common. So, this all I know I have I think set it again and again. So, we have removal by convection air is by itself a very poor heat conductor, it removes heat when streaking over a hot plate. The heat power is conducted to the cooling fin and so, on there it is transferred to the air.

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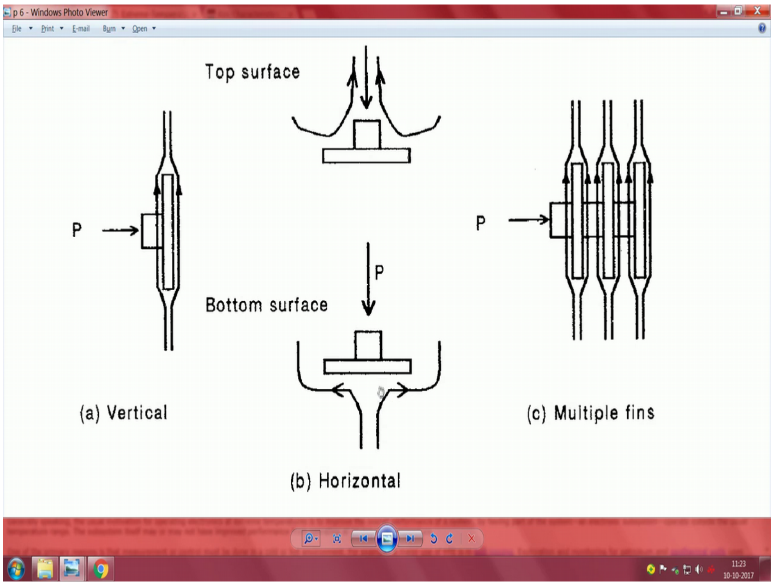

Here we come to several combinations of way things can move.

So, if you have a top surface cool air gets drawn and then goes up and then this you know this arrow here is about the power being put in its not the air flow . So, the power is given here and then this cooling seems to be very convenient. And in the case of bottom surface, we still have a problem a little bit of what you call the voids or pockets form here which prevent air from being circulated. And then you have this normal vertical orientation and multiple fins.

Where these are useful as imagine you have a enclosure which is cash carrying all the heat. So, I have a top surface in which some heat is lost, you have the bottom surface if it is elevated usually have the rubber feet cooling can take place and then extreme left and right surfaces where these things can be improved. Now comes to the other thing is there a way for us to increase the surface area.

So, we come into this for the surface area, we come into this beautiful thing about saying

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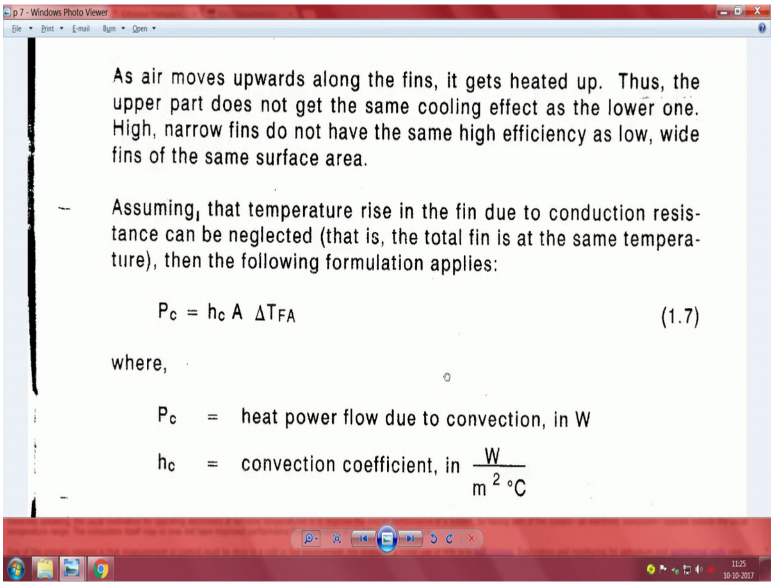

As air moves upwards along the fins, it gets heated up. Thus, the upper part does not get the same cooling effect as the lower one. High, narrow fins do not have the same high efficiency as low, wide fins of the same surface area.

Assuming, that temperature rise in the fin due to conduction resistance can be neglected (that is, the total fin is at the same temperature), then the following formulation applies:

$$P_c = h_c A \ \Delta T_{FA} \qquad (1.7)$$

where,

P_c = heat power flow due to convection, in W

h_c = convection coefficient, in $\frac{W}{m^2 \, ^\circ C}$

Why do not we just put more and more fins. So, if you put more and more fins; obviously, more areas available and then why not put grooves along the fins which I told you in the case of a commercial thing how to make the grooves. If you have to depend only a natural convection; it does help a little. In fact, probably you know it helps a lot; so, here with the process of completion.

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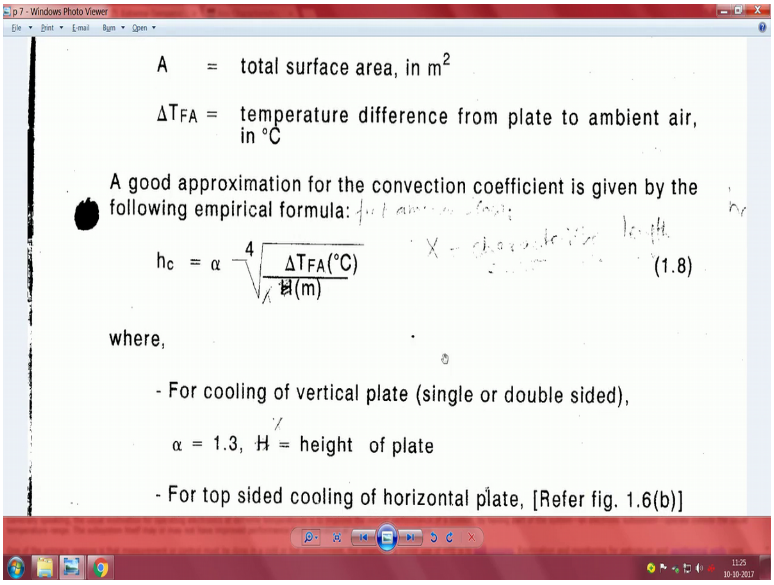

A = total surface area, in m^2

ΔT_{FA} = temperature difference from plate to ambient air, in °C

A good approximation for the convection coefficient is given by the following empirical formula:

$$h_c = \alpha \sqrt[4]{\frac{\Delta T_{FA}(^\circ C)}{H(m)}} \qquad (1.8)$$

X = characteristic length

where,

- For cooling of vertical plate (single or double sided),

  $\alpha = 1.3$, H = height of plate

- For top sided cooling of horizontal plate, [Refer fig. 1.6(b)]

They have given saying how to determine this heat transfer coefficient. We know how much is the power and then if you know the amount of power, we can get delta F into ambient; conversely if you can specify this, what you call fin to ambient you can saw what is the maximum power it is there.

As we go down good approximation for the convection coefficient is given by the empirical formula.

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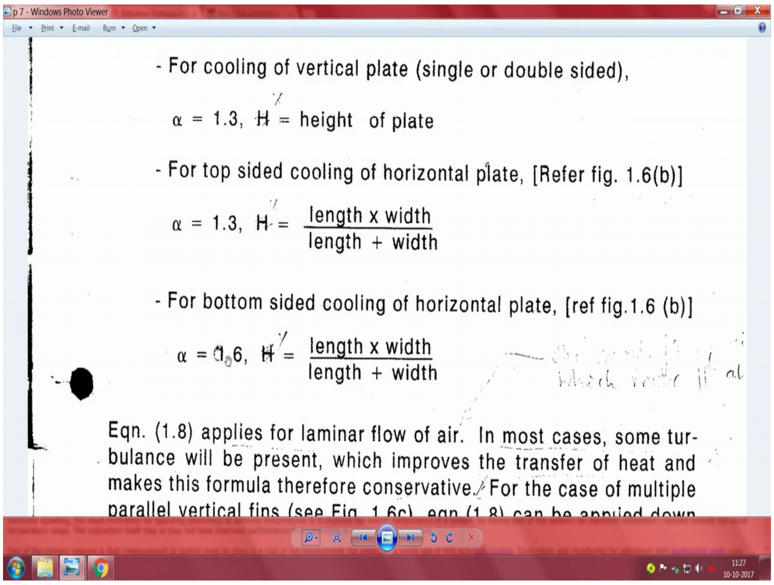

- For cooling of vertical plate (single or double sided),

  $\alpha = 1.3$, H = height of plate

- For top sided cooling of horizontal plate, [Refer fig. 1.6(b)]

  $$\alpha = 1.3,\ H = \frac{\text{length x width}}{\text{length + width}}$$

- For bottom sided cooling of horizontal plate, [ref fig.1.6 (b)]

  $$\alpha = 1.6,\ H = \frac{\text{length x width}}{\text{length + width}}$$

Eqn. (1.8) applies for laminar flow of air. In most cases, some turbulance will be present, which improves the transfer of heat and makes this formula therefore conservative. For the case of multiple parallel vertical fins (see Fig. 1.6c), eqn (1.8) can be applied down

Where for cooling the vertical plate it is 1.3 this one alpha has been introduced here where H is height of plate, the top sided cooling it is this length into width by this. And here there is a small what you call; I will call it a long ago; we did not have a back button, you can never undo things which have done; maybe there is a reason why things made in 1800 are still valid because it was made nothing like know I will correct it tomorrow. It is not like a social networking where it really does not matter.

But this is the original what you call draft copy; which I managed to get. So, alpha in the case of bottom sided cooling comes to 0.6. Now if you ask me how all these numbers came they are all empirical mean somebody has put and in fact, we had that plate a small plate and which is small it was taken; you know for some convenience 150 mm by 150 mm plate square.

And in one variant keeping the total area same 150; 150 which will give you or 225. In another variant one side was you know reduced to 100; other side was made 22 and a small to 3 transistor was mounted and it was made to dissipate heat by keeping it in the linear region.

So, there was a large current flowing and there is a voltage drop and the transistor was getting heated. And at the base of the device, we had resistors and the base drive could be controlled to ensure that the amount of wattage we control; so, these have been formulated. So, see here for a square plate; obviously, H is same, but in the case of a rectangular plate; we have it length into width by length plus width and so on and so, on know.

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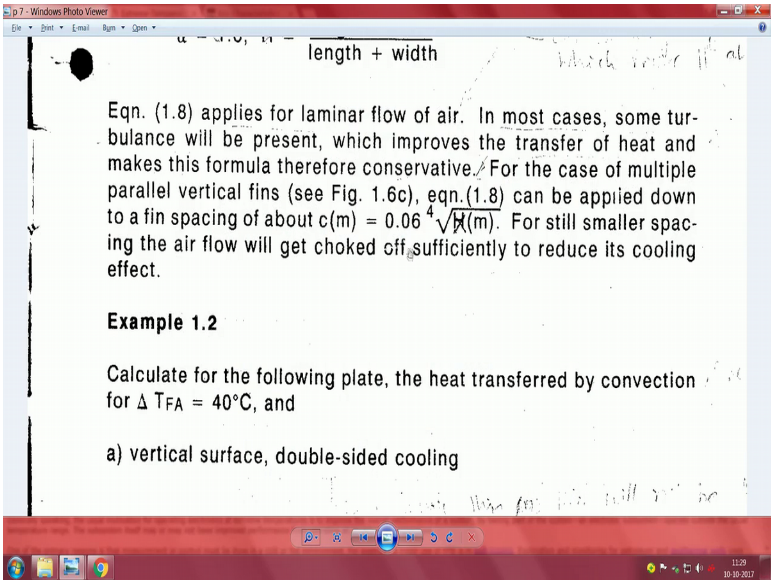

length + width

Eqn. (1.8) applies for laminar flow of air. In most cases, some turbulance will be present, which improves the transfer of heat and makes this formula therefore conservative. For the case of multiple parallel vertical fins (see Fig. 1.6c), eqn.(1.8) can be applied down to a fin spacing of about $c(m) = 0.06 \sqrt[4]{\cancel{H}(m)}$. For still smaller spacing the air flow will get choked off sufficiently to reduce its cooling effect.

Example 1.2

Calculate for the following plate, the heat transferred by convection for $\Delta T_{FA} = 40°C$, and

a) vertical surface, double-sided cooling

We in the end we have come to this interesting thing saying because of multiple vertical fins, the equation can be applied to a fin spacing of about this much; depending on the this alpha for still smaller spacing the airflow get chocked sufficiently to reduce cooling effect .

This is by example by actually running things meaning as I have given an example of a plate which is a 150 mm by 150 mm and they have kept a very very close using some spacers that is phenolic rod was taken . Imagine this a phenolic rod and then slits or cut and then they were kept in a way airflow does not you know what you call get affected. So, the if this were a plate know; so, we have this fins which hold the plates together to in the side top and then one in the middle.

So, that the spacing is maintained and then they were also made very very thin. So, that in the normal place they do not impede the air flow then what has been found out is if you make them slow close nothing can what you call it really does not help . So, we have a worked out example is given here saying for a horizontal surface sorry.

Calculate for a vertical calculate the for the following plate the heat transferred by convection, when already directly the differential between the ambient and the surface of the heat sink is given saying it's around 40 degrees; which is typically what is likely to happen.

In the standard temperature conditions we have 25 degrees. So, the plate can be at 65 degrees, but generally it is a little elevated temperature; imagine the ambient is 55; the plate can still be at 95 degree centigrade which is not a impossible condition.

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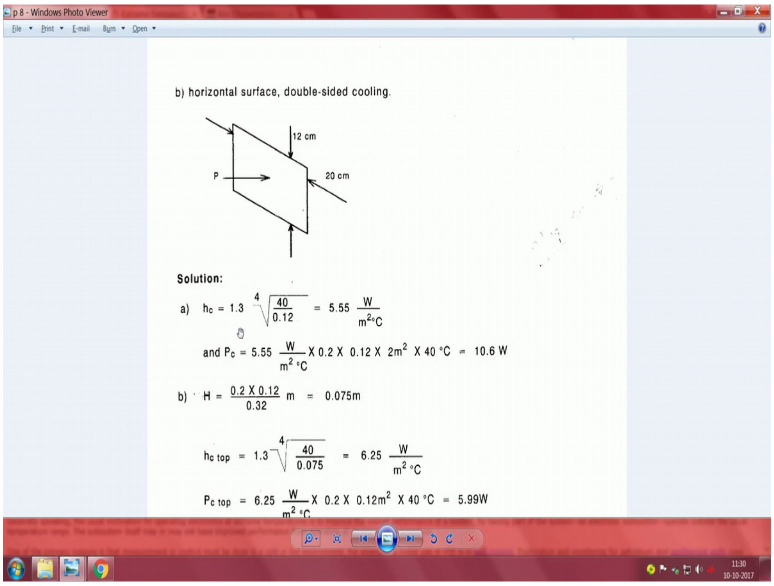

b) horizontal surface, double-sided cooling.

Solution:

a) $h_c = 1.3 \sqrt[4]{\frac{40}{0.12}} = 5.55 \frac{W}{m^2 °C}$

and $P_c = 5.55 \frac{W}{m^2 °C} X\ 0.2\ X\ 0.12\ X\ 2m^2\ X\ 40\ °C = 10.6\ W$

b) $H = \frac{0.2\ X\ 0.12}{0.32}\ m = 0.075m$

$h_{c\ top} = 1.3 \sqrt[4]{\frac{40}{0.075}} = 6.25 \frac{W}{m^2 °C}$

$P_{c\ top} = 6.25 \frac{W}{m^2 °C} X\ 0.2\ X\ 0.12m^2\ X\ 40\ °C = 5.99W$

So, things have been calculated saying in the case of it is in the vertical condition, they have 10 watts.

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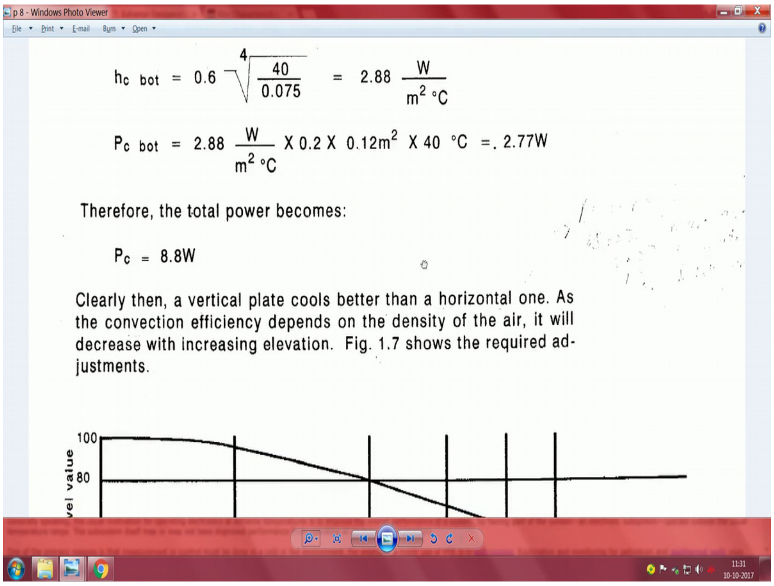

$h_{c\ bot} = 0.6 \sqrt[4]{\frac{40}{0.075}} = 2.88 \frac{W}{m^2 °C}$

$P_{c\ bot} = 2.88 \frac{W}{m^2 °C} X\ 0.2\ X\ 0.12m^2\ X\ 40\ °C =.\ 2.77W$

Therefore, the total power becomes:

$P_c = 8.8W$

Clearly then, a vertical plate cools better than a horizontal one. As the convection efficiency depends on the density of the air, it will decrease with increasing elevation. Fig. 1.7 shows the required adjustments.

And in the case you kept it in the horizontal condition; you are seeing this is 0.3 hm. We have 1.3 for the that alpha 1.3 for the top side condition then we have a 0.6 for the bottom side condition. So, we have approximately 6 plus 2.7 around 8.8 watts can be dissipated; when it is in the vertical condition as compared to 10 watts when it is kept in the vertical.

So, in the horizontal condition know there is a little degradation.

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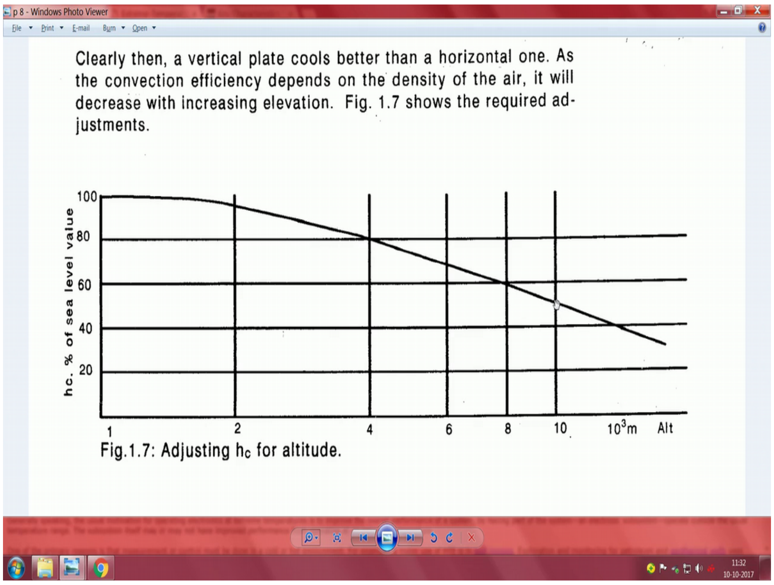

Clearly then, a vertical plate cools better than a horizontal one. As the convection efficiency depends on the density of the air, it will decrease with increasing elevation. Fig. 1.7 shows the required adjustments.

Fig.1.7: Adjusting h_c for altitude.

Vertical plate cools better than a horizontal one as the convection efficiency depends on the density of the air, it will decrease with increasing elevation. So, this I think it’s keep; it keeps on evolving. So, for this slide at this point know just accept it saying the heat transfer coefficient at sea level will ; if you take it as 100 and this is a kilometers at about maybe 5 kilometers, you still have a there is 4 kilometers to 5 kilometers; you still have most of it can be done .

Further, if you go down go up upto 10 kilometers and all the air cooling naturally know; does not occur. It is unlikely that we ever use things at this large altitude meant for normal natural air convection.

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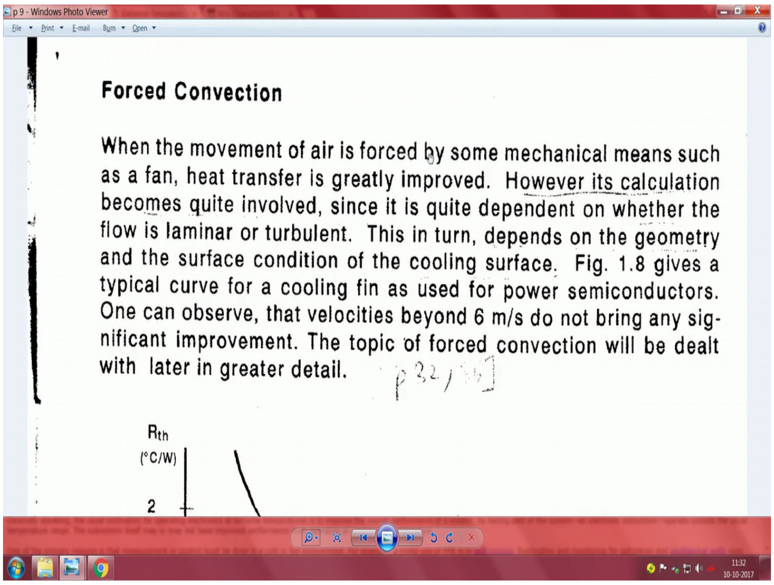

Forced Convection

When the movement of air is forced by some mechanical means such as a fan, heat transfer is greatly improved. However its calculation becomes quite involved, since it is quite dependent on whether the flow is laminar or turbulent. This in turn, depends on the geometry and the surface condition of the cooling surface. Fig. 1.8 gives a typical curve for a cooling fin as used for power semiconductors. One can observe, that velocities beyond 6 m/s do not bring any significant improvement. The topic of forced convection will be dealt with later in greater detail. p 32 / 36]

At this point we come to why not have turbulent and forced convection to make it very very simple; this whole thing has been put in a small graph. When the movement of air is forced by some mechanical means such as a fan; heat transfer is greatly improved.

Its calculation becomes involved why it is mentioned that the calculation becomes involved? Because it is dependent on whether the flow is laminar or turbulent, which in turn depends on the geometry and the surface condition of the surface read it for yourself.

Velocities beyond 6 meters per second do not seem to bring any significant improvement.

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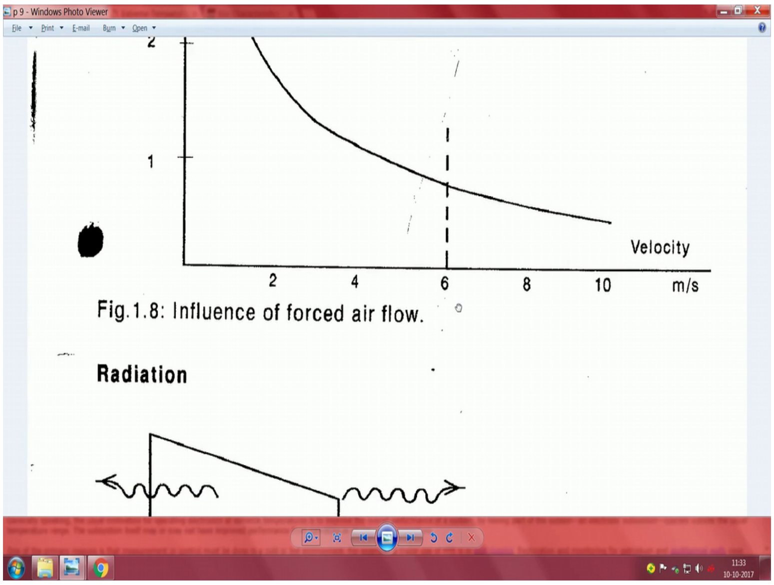

Fig.1.8: Influence of forced air flow.

Radiation

This also an observation.

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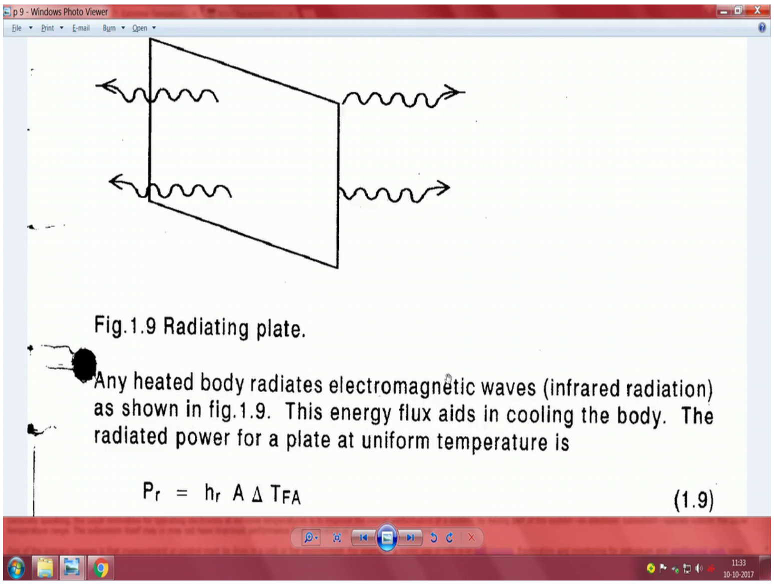

Fig.1.9 Radiating plate.

Any heated body radiates electromagnetic waves (infrared radiation) as shown in fig.1.9. This energy flux aids in cooling the body. The radiated power for a plate at uniform temperature is

$$P_r = h_r A \Delta T_{FA} \qquad (1.9)$$

This also is clearly a simple observation.

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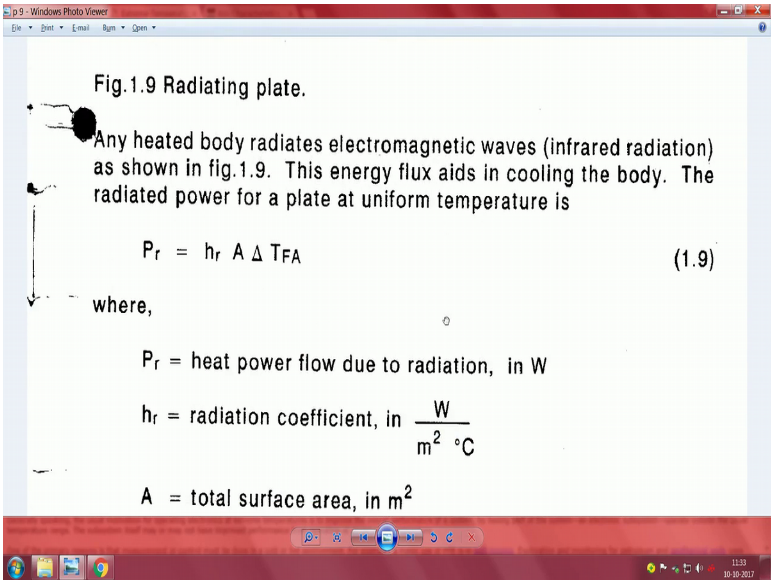

Fig.1.9 Radiating plate.

Any heated body radiates electromagnetic waves (infrared radiation) as shown in fig.1.9. This energy flux aids in cooling the body. The radiated power for a plate at uniform temperature is

$$P_r = h_r A \Delta T_{FA} \qquad (1.9)$$

where,

P_r = heat power flow due to radiation, in W

h_r = radiation coefficient, in $\frac{W}{m^2\ °C}$

A = total surface area, in m^2

For purposes of completing, we have a radiating plate radiation being tech shown here. Any heated body radiates electromagnetic waves which is infrared shown this flux is aids in cooling the body. The radiated power has been shown here, but again I will take it with huge amount of temperature difference radiation coefficient.

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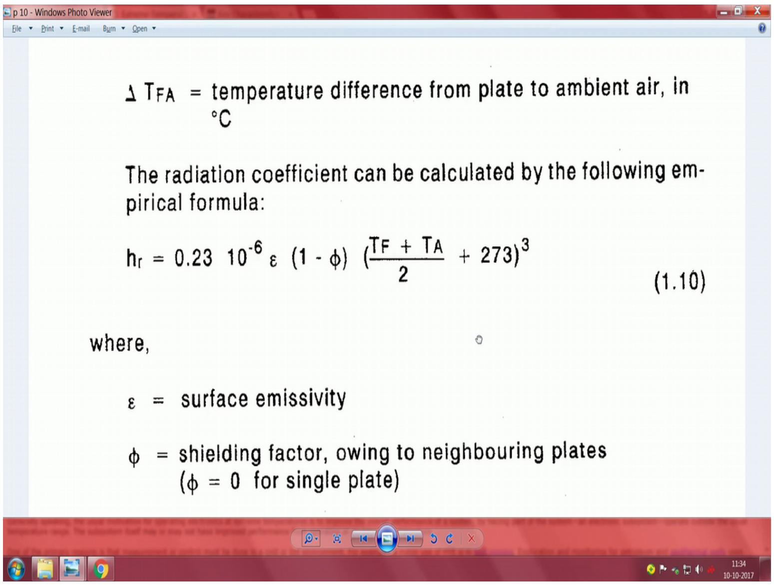

ΔT_{FA} = temperature difference from plate to ambient air, in °C

The radiation coefficient can be calculated by the following empirical formula:

$$h_r = 0.23\ 10^{-6}\ \varepsilon\ (1 - \phi)\ (\frac{T_F + T_A}{2} + 273)^3 \qquad (1.10)$$

where,

ε = surface emissivity

ϕ = shielding factor, owing to neighbouring plates (ϕ = 0 for single plate)

You have seen there is a small what you call catch in it.

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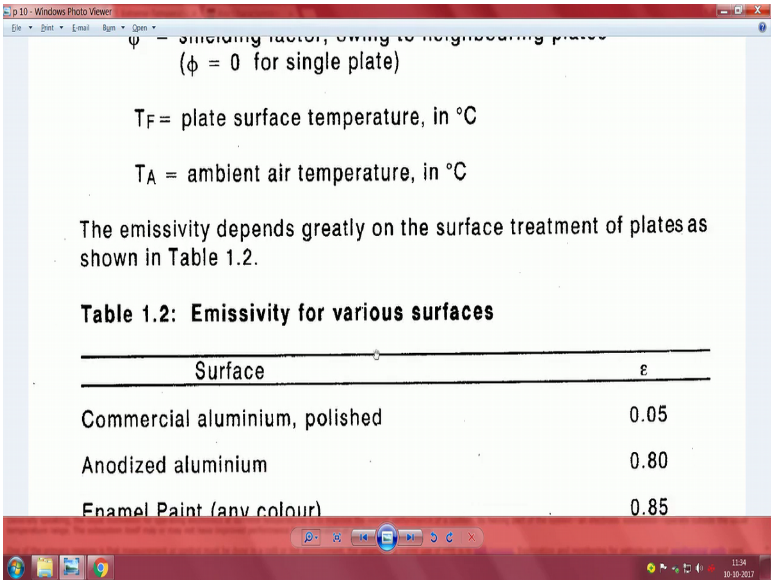

φ = shielding factor, owing to neighbouring plates
(ϕ = 0 for single plate)

T_F = plate surface temperature, in °C

T_A = ambient air temperature, in °C

The emissivity depends greatly on the surface treatment of plates as shown in Table 1.2.

Table 1.2: Emissivity for various surfaces

Surface	ε
Commercial aluminium, polished	0.05
Anodized aluminium	0.80
Enamel Paint (any colour)	0.85

The what you call temperature and these things are inter depend on each other.

So, we have you known surface temperature and so, on and we have this beautiful thing called shielding factor. If they are spaced very closed together one fin shadows the other. So, the shielding factor becomes very very bad.

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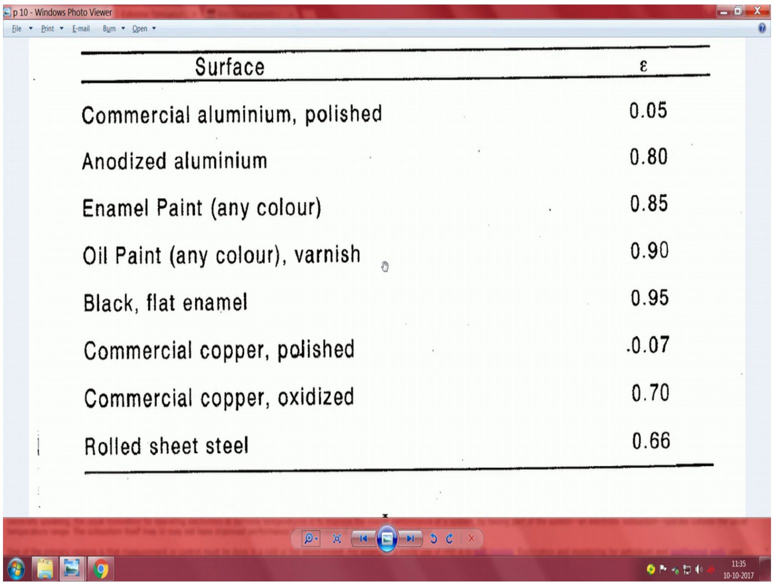

Surface	ε
Commercial aluminium, polished	0.05
Anodized aluminium	0.80
Enamel Paint (any colour)	0.85
Oil Paint (any colour), varnish	0.90
Black, flat enamel	0.95
Commercial copper, polished	.0.07
Commercial copper, oxidized	0.70
Rolled sheet steel	0.66

For showing important things here, this is where you know I kept on stressing from other things permit me one more time to talk about emissivity. Polished aluminum reflects away all the heat, same thing happens with polished copper; seen this no both of them.

Commercial aluminum and commercial copper polished because its worst condition are very good reflectors of heat.

So, I have given you an example of the toaster also; the red toaster, if you look inside you can see the heaters which you know radiate everything. And outside where you touch, you do not feel much of a heat because just underneath that is a aluminum reflector on both sides. Aluminum reflector avoids all this and then by very carefully spacing and then also ensuring that there are no radiant coils on the outside; they manage it well.

And all you need to do is maybe put a slice of bread and you know push it down and all the thing miraculously comes. Depending on how miraculous you are feeling, sometimes it comes chart, but it is still. And you would notice one more very interesting thing in it; interesting patterns are created on the toast by masking part of it inside; that mask itself can be made of another any material aluminum is about best.

So, on the bread if you keep a let us say heart shaped any aluminum foil. And if they will way of it to hold it and do not write and short circuit the thing, when you take it out you will find a beautiful a tost with a heart shape I am sure if you have seen in the movies know all sorts of jumex are used for this.

Now looking back at this here most of the thing here; anodized aluminum emissivity is shown as 0.8. And next to comes the interesting thing here, can you see this? Any color things seems to be any color seems to be the operating definition.

Now, you can go back to what you call the handbooks. And that truth is these numbers are all correct 0.8 to 0.95 are correct. Do not go to blonds where the people copy; posters copy something else from somewhere and then by what you call I did not know it is a devils work or what work know these days drag and drop cut and paste copy and paste is there.

So, somewhere somebody has written saying black is better in some other context maybe. And then maybe equal opportunity and maybe other things that apart; in the case of our radiation, it does not make a difference; if you make a heat sink blacker not understand. Only thing is it should not be polished and if it is dull; it continues to have this pointed.

And paint and oil have still a problem; it is not that easy to make flat enamel means I know what you are likely to find in optical equipment; it is a a paint which you know it does closely to the surface. And from it prevents reflection; so, it seems to be absorbing most of the radiation and in the same condition it also emits all the radiation.

So, if your surface plate is high as in the case of; imagine you have resistors wire will not resistant and all which are encased. And often they are dipped in a ceramic material, they radiate resistor reaching know around 150, 200 degree centigrade is common. And they radiate and this radiation can be picked up by your sensitive small equipment; especially if you have a radial heat spreader.

You have seen that know; the word it is generally made of beryllium copper, it nicely sits snugly on it to 5 can. So, I have this to 5 can and then you have this heat what you call spreader which has radial fins all around.

If you have such a thing very close to a heat emitting high temperature what you call thing like a resistor are there. Occasionally it may be difficult for we to understand know they even use heaters inside the equipment; I have told you about the oven control crystals. So, you have a heater on the outside some many where know it they have a tendency to pick up heat from outside.

It does not radiate then we come to the last point saying rolled sheet steel. Rolled sheet steel is usually know what we keep using the word sheet metal everywhere. The correct technical word is steel which is hot rolled; this is what you get everywhere in which you use it for boxes and all that. It looks like same thing appears there also and you can improve it slightly by this is in the as rolled condition; it has a dull grey, you can improve by putting it with this flat paint which I do not know; sometimes at least here locally known they call it blackboard paint and then the thing which is used inside.

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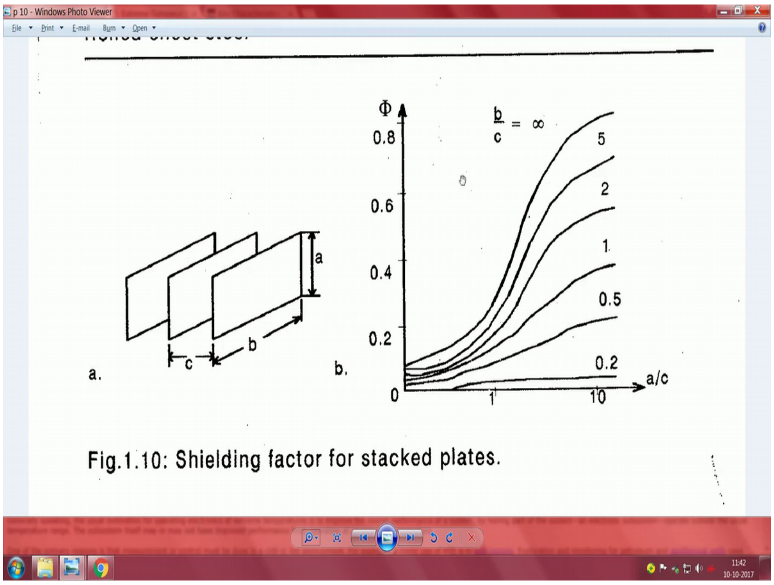

Fig.1.10: Shielding factor for stacked plates.

Next picture shows you shielding factors for different spacing. So, you have b by c you have seen that now b is very long compared to c. Then a; a by c that is a you have here that is a height of it versus a because this is the one if radiation comes and hits this point and then it goes here let me see if this works.

So, you have radiation comes here it comes here and it absorbs. If below this the chances of any radiation hitting here is small and with this a very good absorber; obviously, it cannot give you a total internal reflection.

So, you end up with only the small area and a little in the end what you see here contributing to radiation being useful. So, as you see as the depth keeps increasing; the we have this you know you can see how well the this factor gets was seen this here phi shielding factor going into neighboring plates, as the depth keeps increasing the shielding factor keeps increasing and becomes very high you see here it comes all the way to 0.8.

So, as the total surface as counted for the convection only a week for 20 percent of is available for you for the radiation. And that coupled with the very poor temperature difference will not permit you to what you call depicts things.

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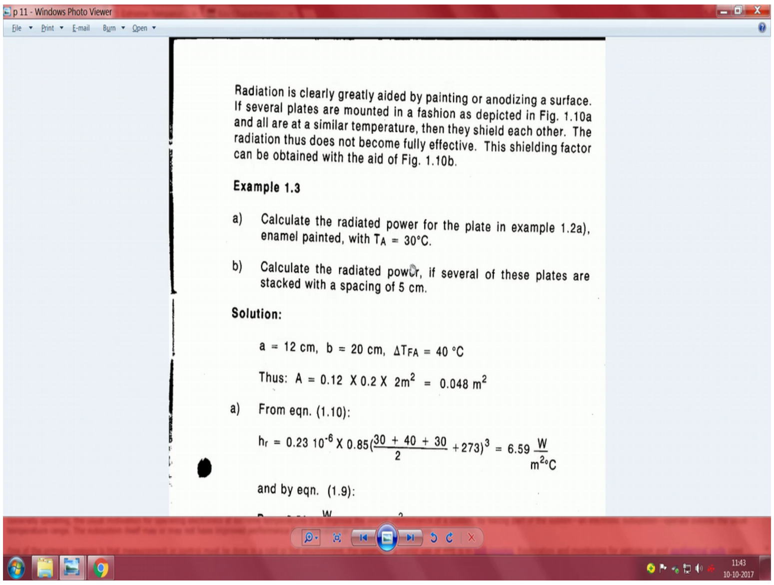

Radiation is clearly greatly aided by painting or anodizing a surface. If several plates are mounted in a fashion as depicted in Fig. 1.10a and all are at a similar temperature, then they shield each other. The radiation thus does not become fully effective. This shielding factor can be obtained with the aid of Fig. 1.10b.

Example 1.3

a) Calculate the radiated power for the plate in example 1.2a), enamel painted, with $T_A = 30°C$.

b) Calculate the radiated power, if several of these plates are stacked with a spacing of 5 cm.

Solution:

$a = 12\ cm,\ b = 20\ cm,\ \Delta T_{FA} = 40\ °C$

Thus: $A = 0.12 \times 0.2 \times 2m^2 = 0.048\ m^2$

a) From eqn. (1.10):

$$h_r = 0.23\ 10^{-6} \times 0.85\left(\frac{30 + 40 + 30}{2} + 273\right)^3 = 6.59\ \frac{W}{m^2 °C}$$

and by eqn. (1.9):

Calculated the radiated power for the plate, calculate the radiate power is several of these are.

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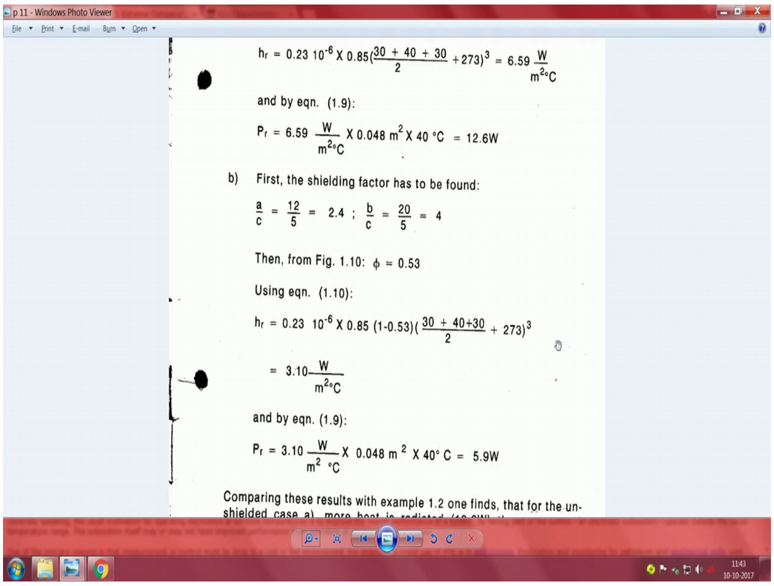

$$h_r = 0.23\ 10^{-6} \times 0.85\left(\frac{30 + 40 + 30}{2} + 273\right)^3 = 6.59\ \frac{W}{m^2 °C}$$

and by eqn. (1.9):

$$P_r = 6.59\ \frac{W}{m^2 °C} \times 0.048\ m^2 \times 40\ °C = 12.6W$$

b) First, the shielding factor has to be found:

$$\frac{a}{c} = \frac{12}{5} = 2.4\ ;\ \frac{b}{c} = \frac{20}{5} = 4$$

Then, from Fig. 1.10: $\phi = 0.53$

Using eqn. (1.10):

$$h_r = 0.23\ 10^{-6} \times 0.85\ (1-0.53)\left(\frac{30 + 40+30}{2} + 273\right)^3$$

$$= 3.10\ \frac{W}{m^2 °C}$$

and by eqn. (1.9):

$$P_r = 3.10\ \frac{W}{m^2\ °C} \times\ 0.048\ m^2 \times 40°\ C = 5.9W$$

Comparing these results with example 1.2 one finds, that for the un-shielded case a) more heat is radiated

Mounted delta FA is maintained. So, total if you attach all those things and all that know you get a figure of around 6 watts you understood.

So, the plate shielding factor is 4 because of the depths using this equation what all is there know.

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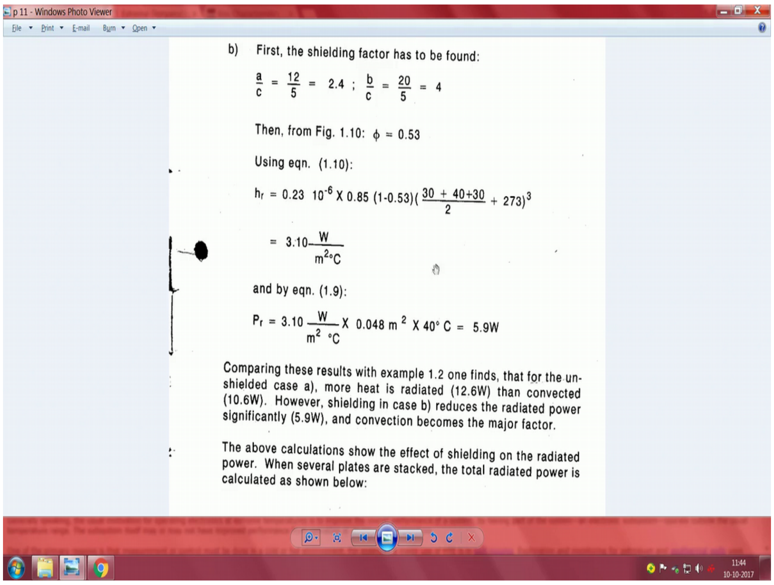

b) First, the shielding factor has to be found:

$\frac{a}{c} = \frac{12}{5} = 2.4$; $\frac{b}{c} = \frac{20}{5} = 4$

Then, from Fig. 1.10: $\phi = 0.53$

Using eqn. (1.10):

$h_r = 0.23 \ 10^{-6} X \ 0.85 \ (1\text{-}0.53)(\frac{30 + 40+30}{2} + 273)^3$

$= 3.10 \frac{W}{m^2 °C}$

and by eqn. (1.9):

$P_r = 3.10 \frac{W}{m^2 \ °C} X \ 0.048 \ m^2 \ X \ 40° \ C = 5.9W$

Comparing these results with example 1.2 one finds, that for the unshielded case a), more heat is radiated (12.6W) than convected (10.6W). However, shielding in case b) reduces the radiated power significantly (5.9W), and convection becomes the major factor.

The above calculations show the effect of shielding on the radiated power. When several plates are stacked, the total radiated power is calculated as shown below:

In the end comparing these results with one finds that for the unshielded case, more heat is radiated then converted. Shielding case reduces the radiated power then convection becomes major factor; above calculation show the effect of shielding in the radiated power and mind you what is shown here as the various what you call the emissivity and those things are still you know; he has taken the best of emissivity here understand 0.85 which is not really true most of the cases.

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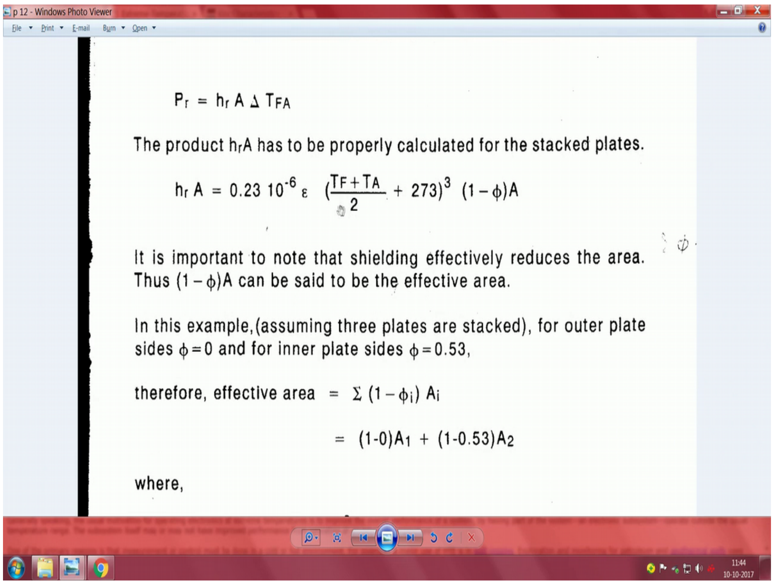

$P_r = h_r A \Delta T_{FA}$

The product h_rA has to be properly calculated for the stacked plates.

$h_r A = 0.23 \ 10^{-6} \ \varepsilon \ (\frac{T_F + T_A}{2} + 273)^3 \ (1 - \phi)A$

It is important to note that shielding effectively reduces the area. Thus $(1 - \phi)A$ can be said to be the effective area.

In this example,(assuming three plates are stacked), for outer plate sides $\phi = 0$ and for inner plate sides $\phi = 0.53$,

therefore, effective area $= \Sigma \ (1 - \phi_i) \ A_i$

$= (1\text{-}0)A_1 + (1\text{-}0.53)A_2$

where,

. So, when you calculated including this emissivity.

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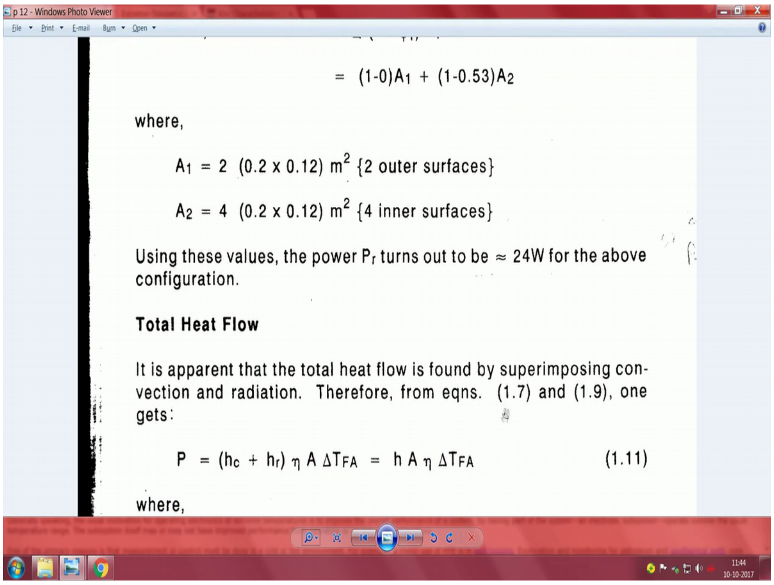

$= (1-0)A_1 + (1-0.53)A_2$

where,

$A_1 = 2\ (0.2 \times 0.12)\ m^2$ {2 outer surfaces}

$A_2 = 4\ (0.2 \times 0.12)\ m^2$ {4 inner surfaces}

Using these values, the power P_r turns out to be ≈ 24W for the above configuration.

Total Heat Flow

It is apparent that the total heat flow is found by superimposing convection and radiation. Therefore, from eqns. (1.7) and (1.9), one gets:

$$P = (h_c + h_r)\,\eta\,A\,\Delta T_{FA} = h\,A\,\eta\,\Delta T_{FA} \qquad (1.11)$$

where,

And so, on and so, on this thing using these values power turns out to be for the above configuration, but again it is only to illustrate a simple example to be worked out and a board for the students is has been done. My own practical thing is you have to be little careful about it.

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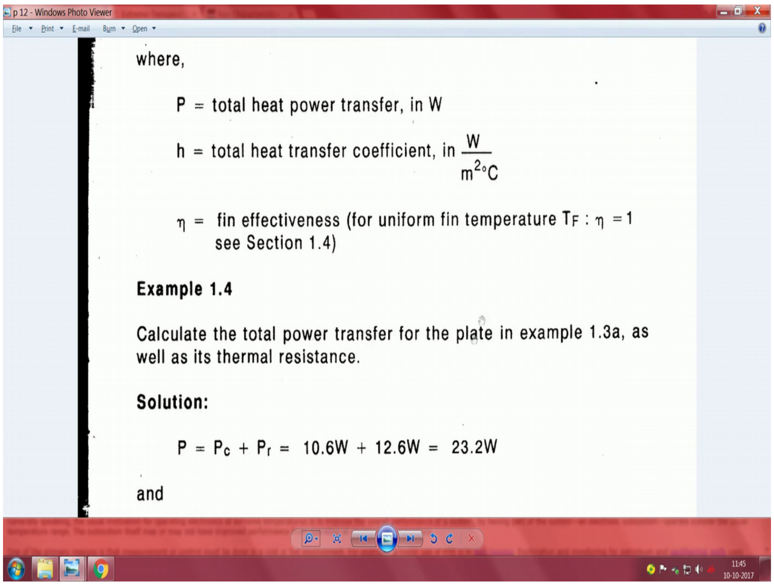

where,

P = total heat power transfer, in W

h = total heat transfer coefficient, in $\frac{W}{m^{2\circ}C}$

η = fin effectiveness (for uniform fin temperature T_F : $\eta = 1$ see Section 1.4)

Example 1.4

Calculate the total power transfer for the plate in example 1.3a, as well as its thermal resistance.

Solution:

$P = P_c + P_r = 10.6W + 12.6W = 23.2W$

and

So, we have a beautiful fin effectiveness and how well calculate the total power for the example and so, on know we have.

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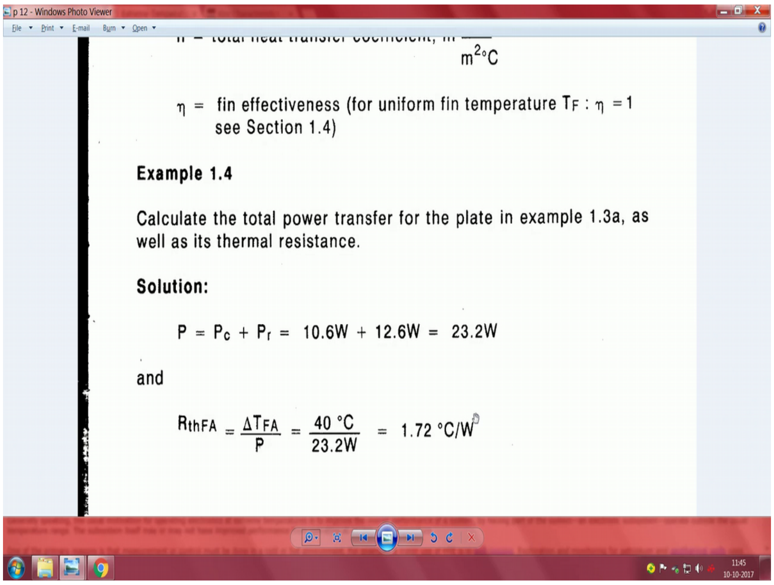

m^2°C

η = fin effectiveness (for uniform fin temperature T_F : $\eta = 1$ see Section 1.4)

Example 1.4

Calculate the total power transfer for the plate in example 1.3a, as well as its thermal resistance.

Solution:

$$P = P_c + P_r = 10.6W + 12.6W = 23.2W$$

and

$$R_{thFA} = \frac{\Delta T_{FA}}{P} = \frac{40\ °C}{23.2W} = 1.72\ °C/W$$

This is the figure you have this 1.72 degrees centigrade per watt has come about. Why this figure is being given is commercial offerings in the market, they would have done all this and then give you saying if you have a stack of plates or an ordinary plate and then if you make things how well they match up.

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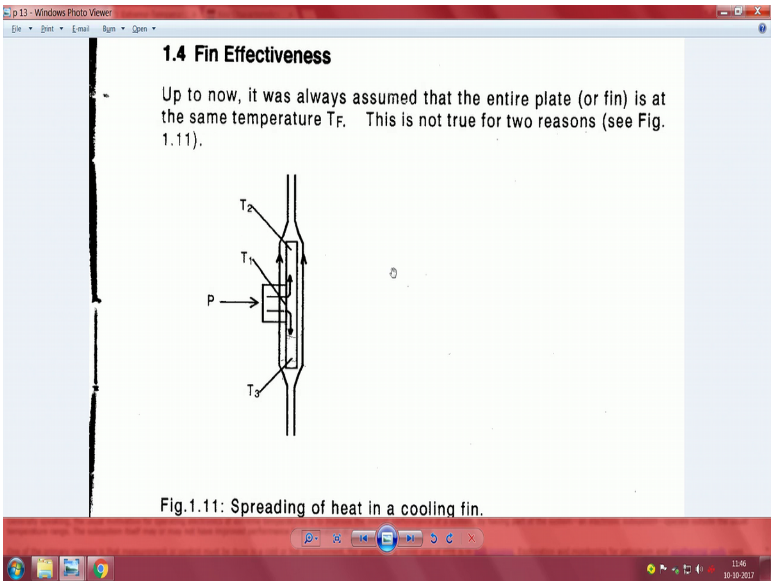

1.4 Fin Effectiveness

Up to now, it was always assumed that the entire plate (or fin) is at the same temperature T_F. This is not true for two reasons (see Fig. 1.11).

Fig.1.11: Spreading of heat in a cooling fin.

We come back to in the earlier chapter; you remember there were pin fins which are having a small square cross section. And then they were fins with a parabolic; parabolic means the fin shape like this ok. Then, you have the other one inverse like this know saying, it is something which is at a per fin.

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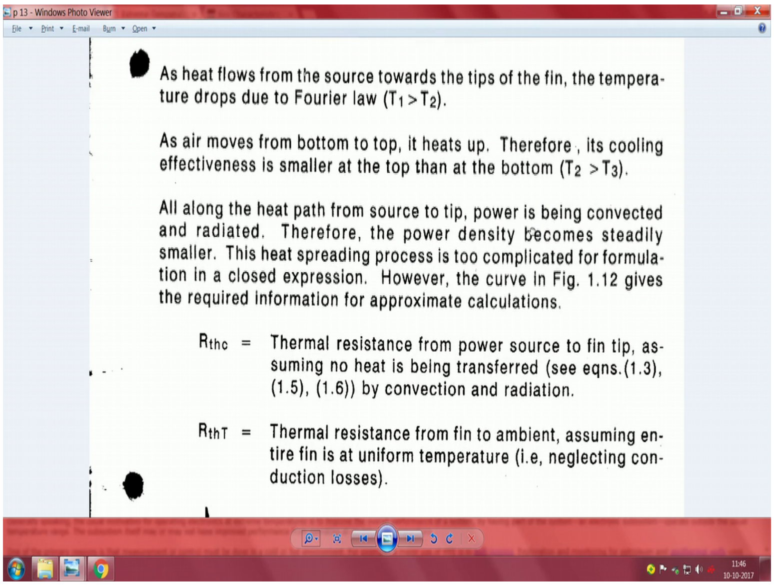

As heat flows from the source towards the tips of the fin, the temperature drops due to Fourier law ($T_1 > T_2$).

As air moves from bottom to top, it heats up. Therefore, its cooling effectiveness is smaller at the top than at the bottom ($T_2 > T_3$).

All along the heat path from source to tip, power is being convected and radiated. Therefore, the power density becomes steadily smaller. This heat spreading process is too complicated for formulation in a closed expression. However, the curve in Fig. 1.12 gives the required information for approximate calculations.

R_{thc} = Thermal resistance from power source to fin tip, assuming no heat is being transferred (see eqns.(1.3), (1.5), (1.6)) by convection and radiation.

R_{thT} = Thermal resistance from fin to ambient, assuming entire fin is at uniform temperature (i.e, neglecting conduction losses).

Why that is all done is we have a regularly showing the way the temperature of these surface changes at the point where the heat enters by conduction you see we have T 1 at that point and the bottom you have T 3 and the top we have T 2; due to conduction and all along slowly conviction is trying to cool the plate.

So, air moves from top top to bottom it heats up therefore, its cooling effector is smaller the top line at the bottom ; which is a very very important thing . Along the heat path source to tip power is being convected and radiated; the power density becomes steadily smaller. This heat spreading process is again sorry for reading it again; here he says it cannot be what he means is too complicated to formulation in a closed expression. In one lone instance; it can be done, but you cannot make a generalized thing for all known things.

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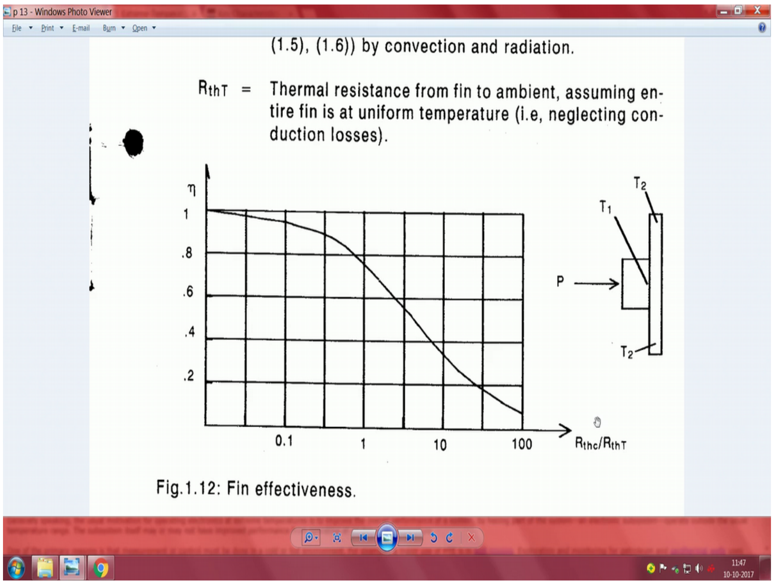

(1.5), (1.6)) by convection and radiation.

R_{thT} = Thermal resistance from fin to ambient, assuming entire fin is at uniform temperature (i.e, neglecting conduction losses).

Fig.1.12: Fin effectiveness.

So, as we go somebody has done this thing the how the efficiency this is by practice

So, we have as the what you call Rthc thermal resistance to the fin tip assuming know heat is being transferred by convection. And thermal resistance fin to ambient assuming entire fin is at uniform temperature.

So, we have depending on this relationship know the efficiency keeps coming down. So, well the flow is what you call my flow has been good, I will just about stop here. So, that I will deal with it later calculate the effectiveness of the aluminum fin I showed in the figure.

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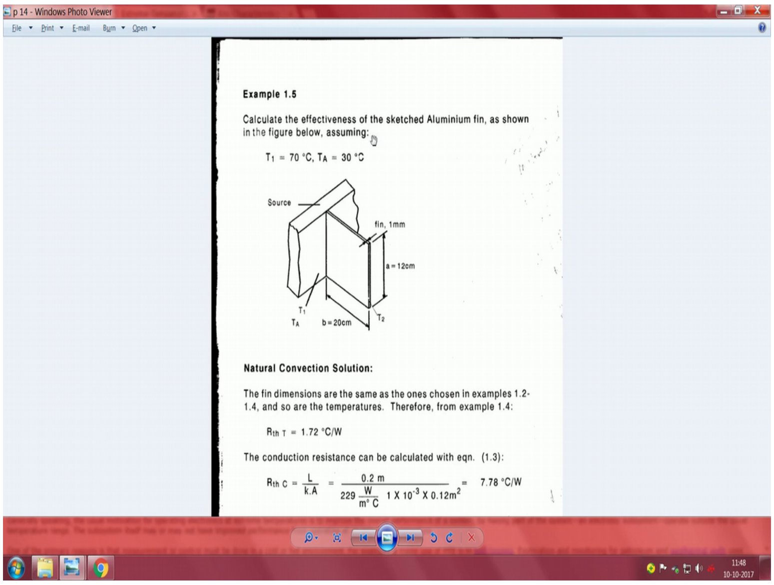

Example 1.5

Calculate the effectiveness of the sketched Aluminium fin, as shown in the figure below, assuming:

$T_1 = 70\ °C,\ T_A = 30\ °C$

Natural Convection Solution:

The fin dimensions are the same as the ones chosen in examples 1.2-1.4, and so are the temperatures. Therefore, from example 1.4:

$R_{th\ T} = 1.72\ °C/W$

The conduction resistance can be calculated with eqn. (1.3):

$$R_{th\ C} = \frac{L}{k.A} = \frac{0.2\ m}{229\ \frac{W}{m°\ C}\ 1 \times 10^{-3} \times 0.12 m^2} = 7.78\ °C/W$$

He has given ambient of 70 degrees and I am sorry the source is 70 degrees and the ambient is 30 and we have this 20 by 12 effects.

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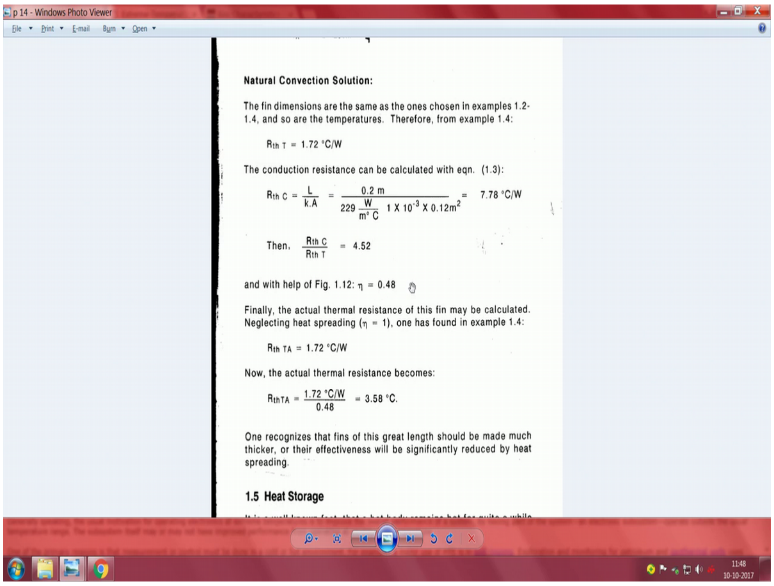

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$$\text{Then,}\quad \frac{R_{th\ C}}{R_{th\ T}} = 4.52$$

and with help of Fig. 1.12: $\eta = 0.48$

Finally, the actual thermal resistance of this fin may be calculated. Neglecting heat spreading ($\eta = 1$), one has found in example 1.4:

$R_{th\ TA} = 1.72\ °C/W$

Now, the actual thermal resistance becomes:

$$R_{thTA} = \frac{1.72\ °C/W}{0.48} = 3.58\ °C.$$

One recognizes that fins of this great length should be made much thicker, or their effectiveness will be significantly reduced by heat spreading.

1.5 Heat Storage

So, the convection solution gives you conduction resistance and then the efficiency 2.48, but you see here the actual thermal resistance becomes this thing, but a lot of it depends on efficiency here which you understood know; we have read from a table neglecting heat spreading one has found the example . And then if you include what you call fins of this great length should be made much thicker or their effectiveness will be significantly reduced by heats spreading.

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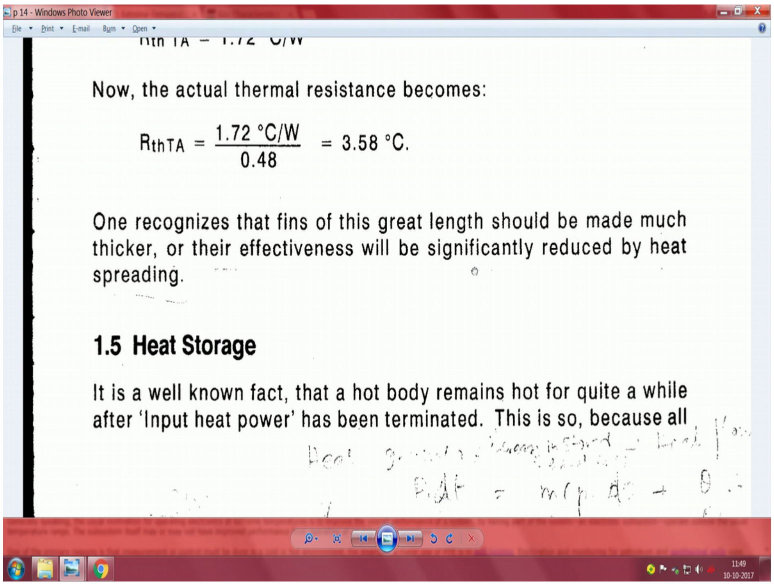

Now, the actual thermal resistance becomes:

$$R_{thTA} = \frac{1.72\ °C/W}{0.48} = 3.58\ °C.$$

One recognizes that fins of this great length should be made much thicker, or their effectiveness will be significantly reduced by heat spreading.

1.5 Heat Storage

It is a well known fact, that a hot body remains hot for quite a while after 'Input heat power' has been terminated. This is so, because all

Heat [illegible] = [illegible] + heat [illegible]

$P.dt = mC_p\, dT + \theta$

I will repeat it again and from here onwards, we end up with the capacitive part of it which is at least in my domain or expertise; only if you are semiconductor person working with known what you call participation and all that or more for the making the analysis complete. So, we have you know slug and how long does it take and so on. And then we have the equivalent circuits and how these things work.

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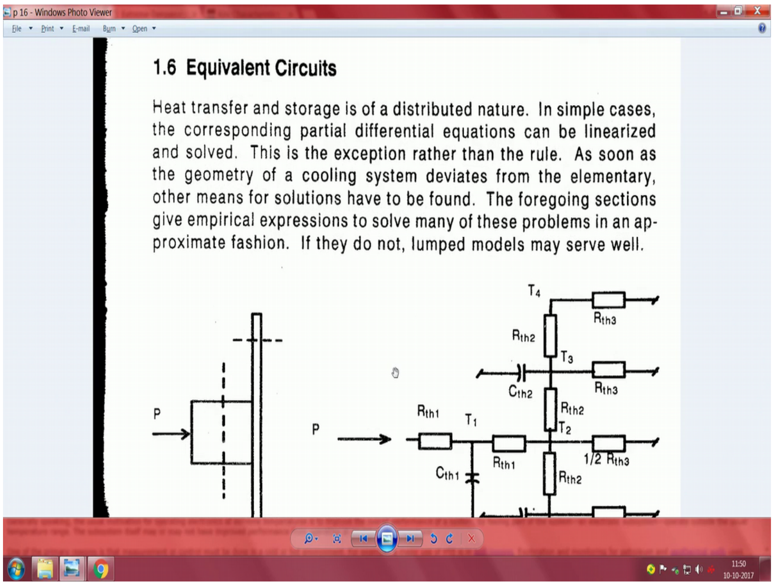

1.6 Equivalent Circuits

Heat transfer and storage is of a distributed nature. In simple cases, the corresponding partial differential equations can be linearized and solved. This is the exception rather than the rule. As soon as the geometry of a cooling system deviates from the elementary, other means for solutions have to be found. The foregoing sections give empirical expressions to solve many of these problems in an approximate fashion. If they do not, lumped models may serve well.

So, thank you I will stop here the equivalent circuits and dealing with it I will see how best I can you know take it up ah. So, thank you. So, thank you I will continue this lecture in the subsequent lectures because that is something which is which is best dealt separately.

So, far what I have talking to you is about how in a simple way we can calculate if a plate standard plate is taken and so on. And if we already have some equivalent relationship by which the efficiency or fin effectiveness versus those things are all known as close approximation has been presented here. And real life things are little slightly different we will continue next time.

Thank you.