Electronics Enclosures Thermal Issues

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Lecture - 19
Fan cooling

We have, examined one from the industry source about how to use fans and. So, on considerable effort has gone into how to actually create a small setup by which you find out the system characteristics of a small enclosure. So, typically a system could be a rack, which has a lot of sub racks, which in turn has printed wiring boards or other things and then you have power supplies and so on.

So, then lot of it has been talked about and or whether you need to blow it, from the bottom or settings from the top and a little bit about filtration and then an ideal, I setup one a plenum chamber and how do you, find out what actually is the flow rate, flow rate inside by putting a small, YouTube manometer, symbolically there from YouTube manometer, because you can vary the pressure and you can, I mean it is calibrated in terms of head and you can do it and other side the actual system pressure and some like that.

As I pointed out earlier, it is on a fully populated board, if you do it, it will be good, this is where initially in that same old slides, I have shown about saying, why cannot we have a concurrent thermal engineering of electronic equipment. Yes, it is easier said, than done, if you know that something is already there existing you can copy. Now, let me go back to a little bit of the what we call theoretical things once more.

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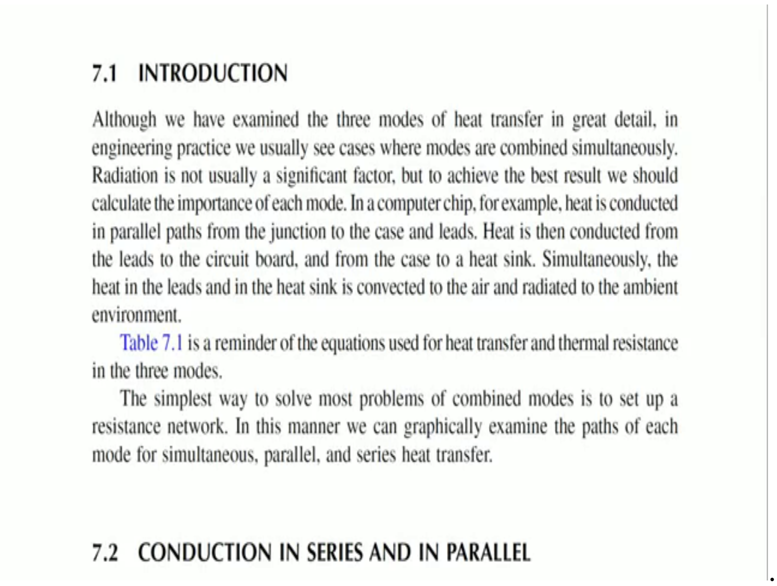

7.1 INTRODUCTION

Although we have examined the three modes of heat transfer in great detail, in engineering practice we usually see cases where modes are combined simultaneously. Radiation is not usually a significant factor, but to achieve the best result we should calculate the importance of each mode. In a computer chip, for example, heat is conducted in parallel paths from the junction to the case and leads. Heat is then conducted from the leads to the circuit board, and from the case to a heat sink. Simultaneously, the heat in the leads and in the heat sink is convected to the air and radiated to the ambient environment.

Table 7.1 is a reminder of the equations used for heat transfer and thermal resistance in the three modes.

The simplest way to solve most problems of combined modes is to set up a resistance network. In this manner we can graphically examine the paths of each mode for simultaneous, parallel, and series heat transfer.

7.2 CONDUCTION IN SERIES AND IN PARALLEL

And you have a look at the fans and sense things, which I have collected here, earlier one of things.

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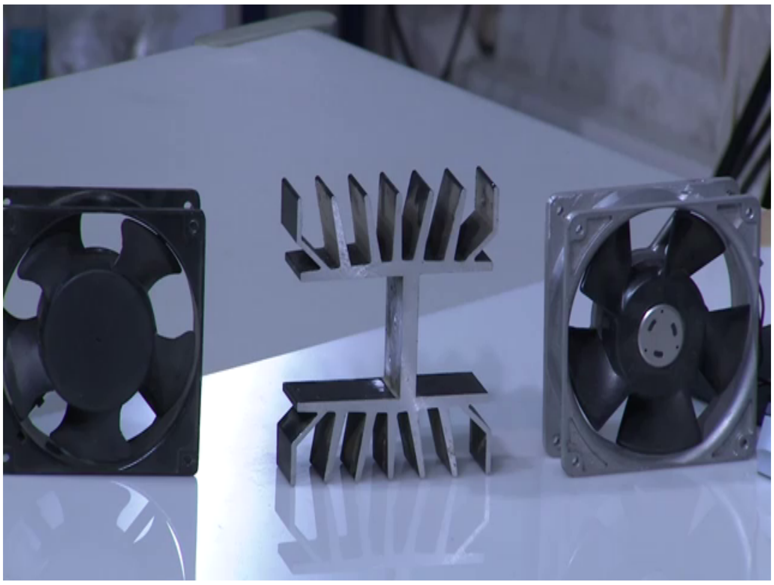

You will notice is we have two fans here, symbols we have one air circulator, I will show it like this similarly, I have one more air circulator here and then we have a heat sink by this all the more, what we call important, that we notices is if we now look at this heat sink, seen this several things come to our notice, one of the first thing that we come to our notice is, as we have quite easily observed, you know there is the base plane, I want to call place for conduction has been thick and. So, from here, you have almost things, which run instead of parallel, you know slightly inclined and all this is easily understandable.

And you see this is almost normal to this bend and then depending on the method of manufacture and all that. So, you have two fans here, this is made black and this is some other thing, something which, you may appreciate. Now, is that you seen this last two fins, this and in the other two fins that not exactly like the fins, which are the other way. So, because there also used for mounting, we cannot effort to have anything mounted here. We have a problem, because serviceability is a serious issue.

So, when we keep this, what you call this air circulator here and then in line, because right now, you need to what we call player on the little bit with it, one thing you will notice is when you want access, this you should be able to remove it without any problem or in the case of hot plug in whole thing, you remove and then supplier is something else, something else, which is very real, is if you see the base can, you see the base here.

It is mounted onto something maybe hrc are something else, thing is this also aids in cooling, when you do not have too much surface area and do not have all this now, every little bit, what we have here, we should be able to make use enough it.

So, the hence works, the correlations are very valid. So, here is I mean, I will kindly read it along with me, where examine three modes in great detail, engineering practice. See cases, where more than the combined simultaneously, radiation is not a significant factor, but to best to achieve best result, we should calculate the importance of each mode.

For example, heat is conducted in parallel paths from the junction to the case heat is then conducted from leads to the circuit board and from the case to a heat sink. Simultaneously, the heat in the leads and the heat sink is convicted to the air and radiated to the ambient environment, this is where we try to point out. I hope you had a chance to look up the golden dragon led or the Luxeon, power led, which is mounted on a star heat sink, one of the maze most of the those LEDs have a copper slug the bottoms; So, that you can attach it to it.

Another is the leads are the tabs themselves conduct away heat and in the case of the small things have no other choice, but to have the heat dissipated wire the printed wiring board and on the printed wiring board, we have copper. So, there some way of making use of that slug in the middle and also making use of these article leads, it is very-very good for us ok.

So, just as an example instead of my showing you and asking a question and answer saying; how do you do it? I suggest you, look up again, look for golden dragon LED, also Luxeon the, what we call 3 watt LED with heat sink there? In their application manual everything is been given very-very well.

Same thing is covered here, saying heat in the leads and the heat sink is convicted to the air and radiated to the ambient environment in the case you have a device like a single in chip or T o 220 various other things, we have lot of parallel paths. So, only way to make up for the parallel paths is to solve the problems of combined modes setup, a resistant network. We can graphically examine the paths of each mode for simultaneous parallel and heat transfer.

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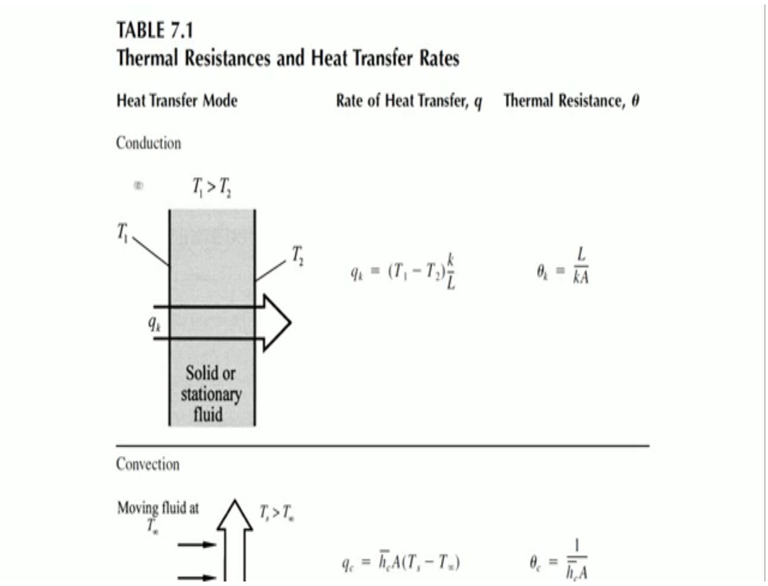

TABLE 7.1
Thermal Resistances and Heat Transfer Rates

Heat Transfer Mode	Rate of Heat Transfer, q	Thermal Resistance, θ
Conduction	$q_k = (T_1 - T_2)\frac{k}{L}$	$\theta_k = \frac{L}{kA}$
Convection	$q_c = \bar{h}_c A(T_s - T_\infty)$	$\theta_c = \frac{1}{\bar{h}_c A}$

So, both are given simple solid or stationary fluid, the T 1 is greater heat transfer. We have seen this earlier, this is simplest. What you can talk about in the conduction mode basically? In conduction, this is the simplest and in the case of convection.

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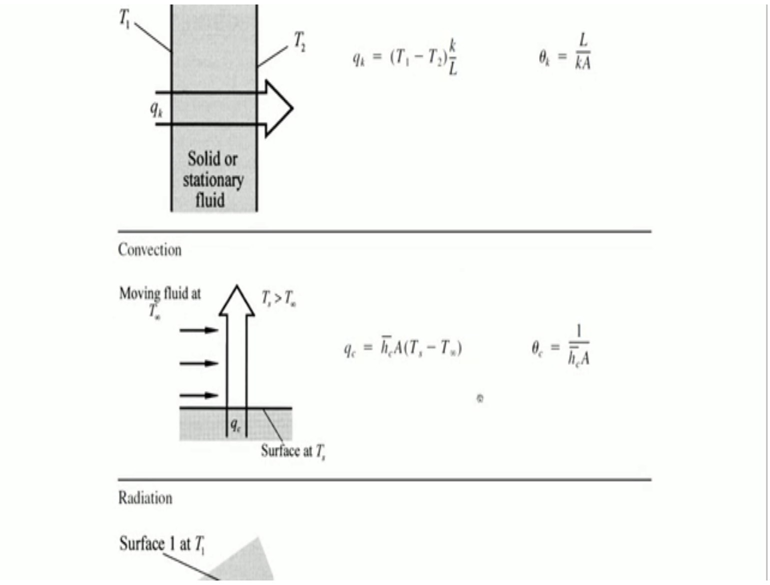

$$q_k = (T_1 - T_2)\frac{k}{L} \qquad \theta_k = \frac{L}{kA}$$

Convection

$$q_c = \bar{h}_c A(T_s - T_\infty) \qquad \theta_c = \frac{1}{\bar{h}_c A}$$

Radiation

We also have again, everything has been to make us very convenient, everything has been made into a lumped heat transfer coefficient in convection and there is an area and a temperature difference.

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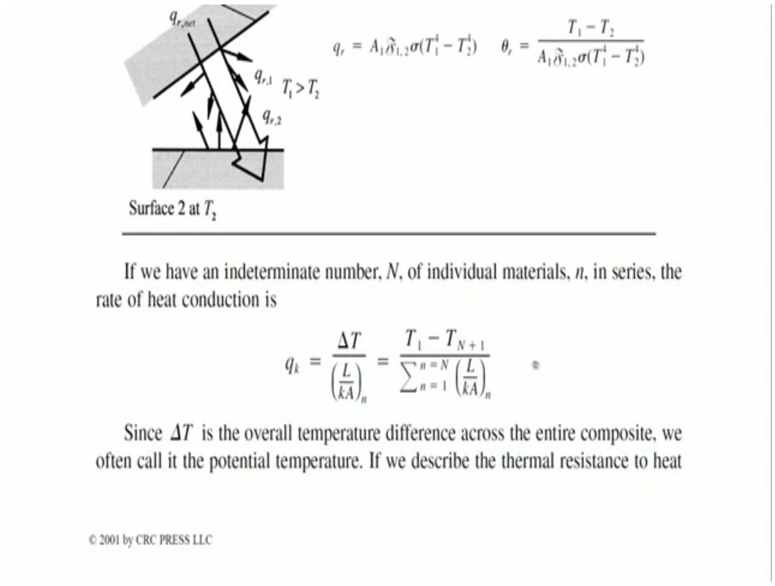

$$q_r = A_1 \tilde{\mathcal{F}}_{1,2}\sigma(T_1^4 - T_2^4) \qquad \theta_r = \frac{T_1 - T_2}{A_1 \tilde{\mathcal{F}}_{1,2}\sigma(T_1^4 - T_2^4)}$$

If we have an indeterminate number, N, of individual materials, n, in series, the rate of heat conduction is

$$q_k = \frac{\Delta T}{\left(\frac{L}{kA}\right)_n} = \frac{T_1 - T_{N+1}}{\sum_{n=1}^{n=N}\left(\frac{L}{kA}\right)_n}$$

Since ΔT is the overall temperature difference across the entire composite, we often call it the potential temperature. If we describe the thermal resistance to heat

Same thing even this you know is about including lot of you know shielding factors and totally finally, you have the total area and then you have all this various type of thing and the temperatures, where thermal resistance, in radiation is given here, in convection is given here and conduction k is you know conduction. This is convection, to make it, this thing; we have indeterminate number of individual materials.

The rate of heat conduction is, they try to make it into a large equation delta T is the overall temperature difference across entire composite. We often call it a potential temperature.

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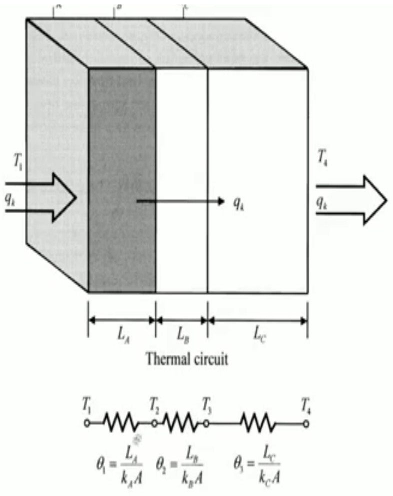

FIGURE 7.1 Thermal conduction through a three-layer system in series.

We describe the thermal resistance. So, you have material A, B, C.

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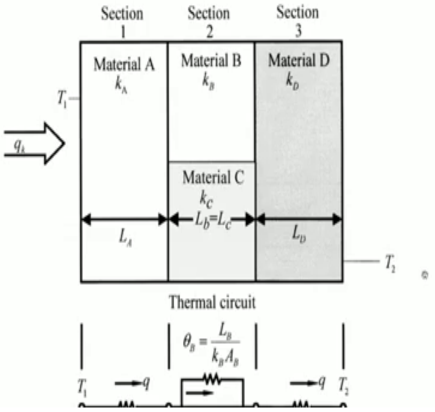

And then by just joining these resistances of different materials, we come out with, this sort of equations.

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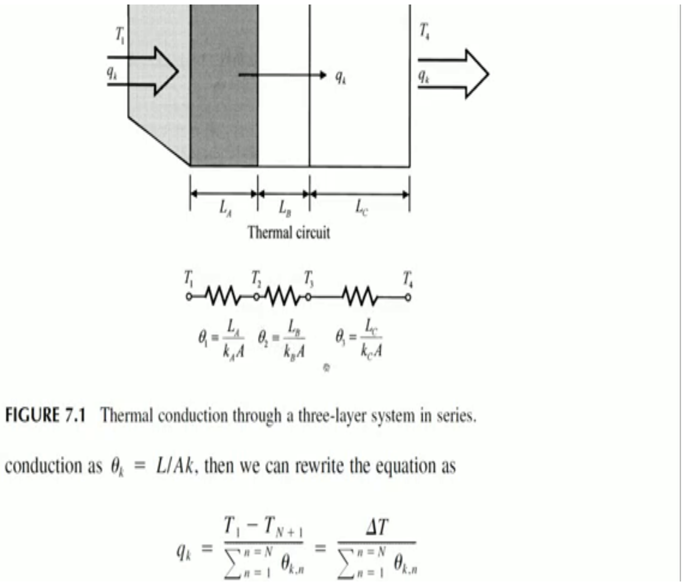

FIGURE 7.1 Thermal conduction through a three-layer system in series.

conduction as $\theta_k = L/Ak$, then we can rewrite the equation as

$$q_k = \frac{T_1 - T_{N+1}}{\sum_{n=1}^{n=N} \theta_{k,n}} = \frac{\Delta T}{\sum_{n=1}^{n=N} \theta_{k,n}}$$

So, we have an A and B and you know different, you know any other material, material you know C and nothing, it is just by adding in it is obvious stating the obvious. We can write the equation saying total power is you know temperature minus all the summation of all these things.

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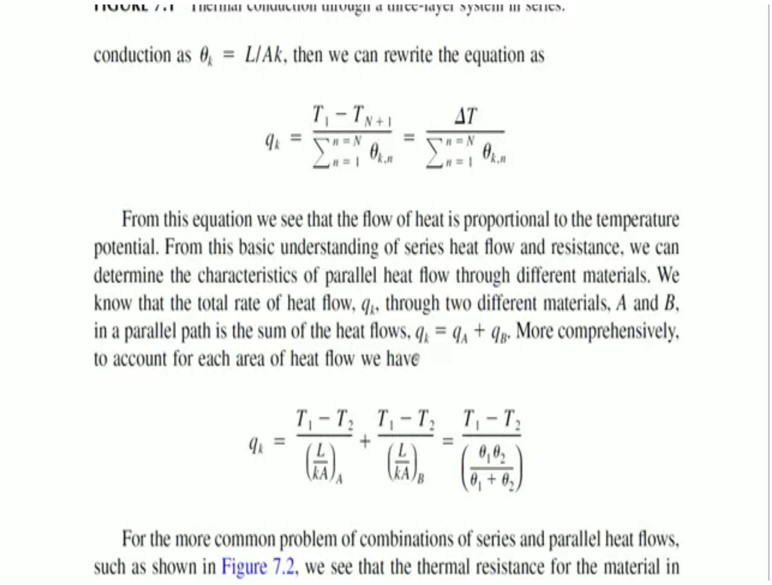

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From this equation we see that the flow of heat is proportional to the temperature potential. From this basic understanding of series heat flow and resistance, we can determine the characteristics of parallel heat flow through different materials. We know that the total rate of heat flow, q_k, through two different materials, A and B, in a parallel path is the sum of the heat flows, $q_k = q_A + q_B$. More comprehensively, to account for each area of heat flow we have

$$q_k = \frac{T_1 - T_2}{\left(\frac{L}{kA}\right)_A} + \frac{T_1 - T_2}{\left(\frac{L}{kA}\right)_B} = \frac{T_1 - T_2}{\left(\frac{\theta_1 \theta_2}{\theta_1 + \theta_2}\right)}$$

For the more common problem of combinations of series and parallel heat flows, such as shown in Figure 7.2, we see that the thermal resistance for the material in

Flow of heat is proportional to the temperature potential from the basic understanding of series heat flow and resistance determine the characteristics of parallel heat flow, through different materials.

So, we know that the total rate of heat flow, through different materials more comprehensively of each of the thing, so on. So, only difference here is we have two paths here, seen this we have a material here and the material here and path here, typically where does it occur? It is not as if, these numbers you know are thick like material installation or your house installation or I keep going in the examples of the domestic refrigerator.

It is more like thin small cross section of the order of millimetres and less the case of chips are all hundreds of micron. There is about point 1 millimetres in the case of light chips. It is a little higher and in the case of when you are coming to sub racks and then you are coming to actual racks dimensions are little slightly bigger thicknesses are usually of the order of 1.6 to 2 to 3 millimetres.

So, if you see my heat sink also here, the thicknesses are slightly different. So, I have a heat sink thickness here, appears to be around 3 millimetres, then the whole thing is mounted on a another plate. So, here comes the design, compromise again, your directly mount it on a plate, if you mount it on a plate here, directly and if it is a conductor, you need to isolate the devices here and you end up with a bigger problem, you understand any small thickness here, is going to cause a lot of problem instead, why not? Mount the device directly here, with only, without an insulator apply, you know pressure and directly especially, when you have things like a far diode stud, diode you know choice, but to directly mounted here.

If you mount it here, because of the direct potential difference, the amount of flow, what you can heat, you know the heat flowing inside will be much better inside, thermal resistance comes down drastically and you will be forced to isolate digits at that point. So, this one instead of directly contacting, the external; what we call word? You can probably have an insulator here, insulator here and then you join it here.

Now, we have the, both the advantages and disadvantages of how do you model this? How does heat start here, go here, go all here, spread all the way here and go also into the small thing and how much of it is related directly?

How much of it will come out? Which is it seems to be our important, factor. Got it? Again, this is where the source of this different materials and different choices are there, which we, talking about.

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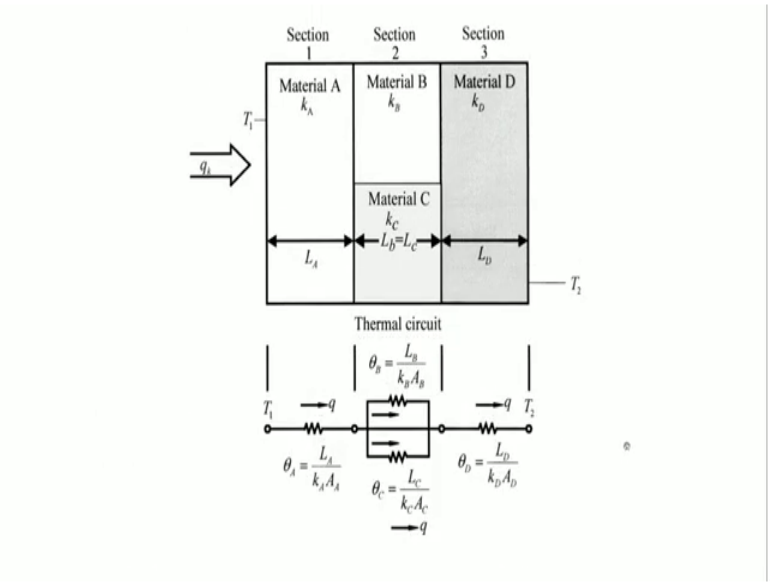

So, you know thermal circuit and which to parallel resistance are there.

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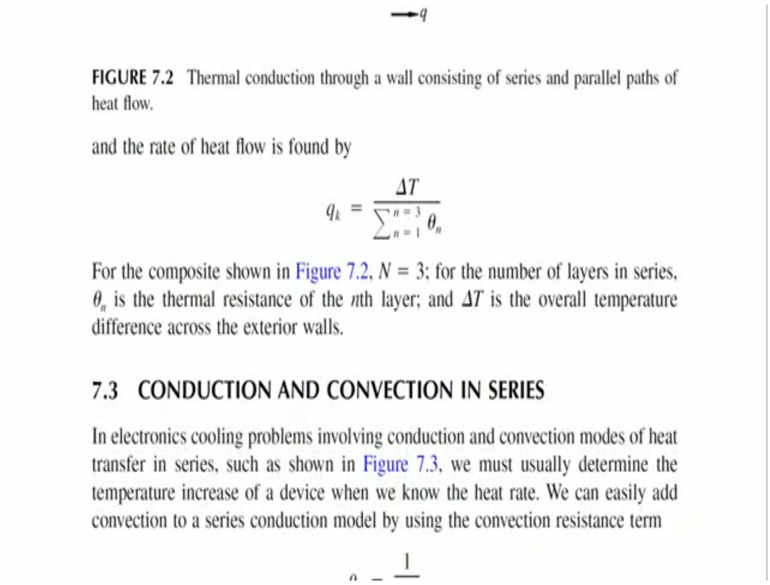

FIGURE 7.2 Thermal conduction through a wall consisting of series and parallel paths of heat flow.

and the rate of heat flow is found by

$$q_k = \frac{\Delta T}{\sum_{n=1}^{n=3} \theta_n}$$

For the composite shown in Figure 7.2, $N = 3$; for the number of layers in series, θ_n is the thermal resistance of the nth layer; and ΔT is the overall temperature difference across the exterior walls.

7.3 CONDUCTION AND CONVECTION IN SERIES

In electronics cooling problems involving conduction and convection modes of heat transfer in series, such as shown in Figure 7.3, we must usually determine the temperature increase of a device when we know the heat rate. We can easily add convection to a series conduction model by using the convection resistance term

If you go down for the number of layers in series, is thermal resistance of nth layer is over a temperature difference. Similarly, since everything has been reduced to a simple heat transfer coefficient, there is an area involved and there is a heat transfer coefficient in each mode.

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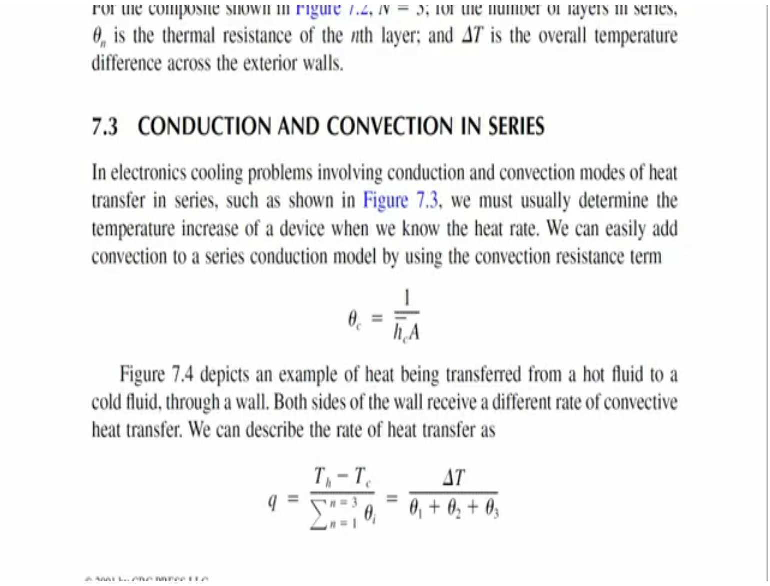

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$$\theta_c = \frac{1}{\bar{h}_c A}$$

Figure 7.4 depicts an example of heat being transferred from a hot fluid to a cold fluid, through a wall. Both sides of the wall receive a different rate of convective heat transfer. We can describe the rate of heat transfer as

$$q = \frac{T_h - T_c}{\sum_{n=1}^{n=3} \theta_i} = \frac{\Delta T}{\theta_1 + \theta_2 + \theta_3}$$

Similar way, if you want to have a both conduction and convection ok, this is the convective heat transfer. How you attach all these things together?

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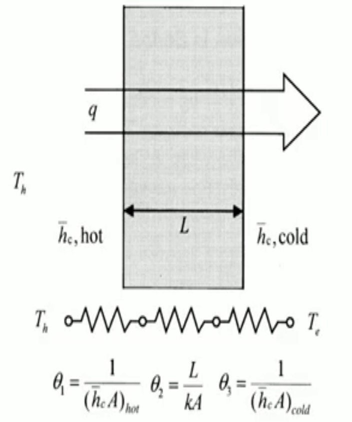

FIGURE 7.4 Heat transfer from a hot gas to a cold gas through a plane wall.

And from a hot gas to a cold gas, through a plane wall, this is typically, I told you about the panel mounted air conditioners, if you to have a communication rack, sometimes you have no other choice, but to remove usually the air panel, if it is a close air panel, you remove the air panel and then put this directly panel mounted air conditioner on the back air conditioner thickness. The big ones are about 200 mm; the smaller one may be around 150 mm.

This is 150 mm, 200 is about this much and then with this usually 400 mm height can vary up to 2 meters that is 6 feet. So, you put it at the back of the thing and there you have a working fluid on the outside and then you have a working fluid on the inside other than this you also have all the walls, freely conducting also outside.

So, if you have a wall thickness, you have a hot side and cold side and how these things, all these, if you know the actual property of the materials.

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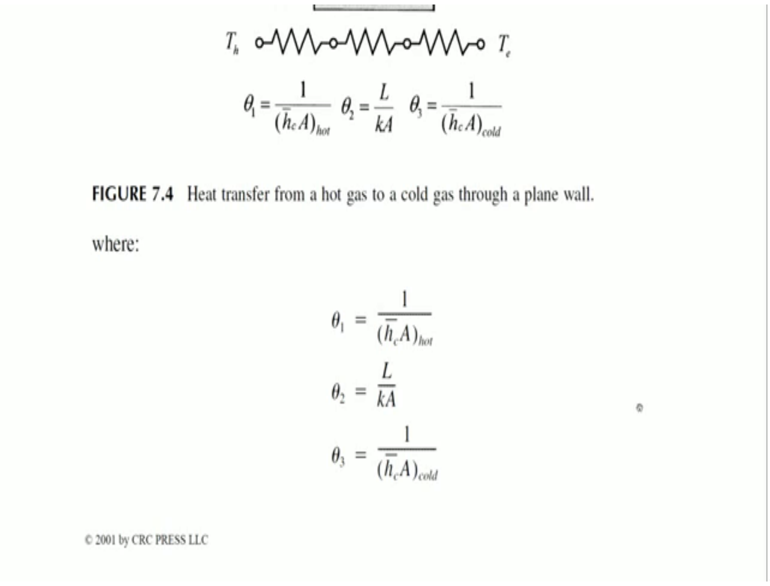

$\theta_1 = \frac{1}{(\bar{h}_c A)_{hot}}$ $\theta_2 = \frac{L}{kA}$ $\theta_3 = \frac{1}{(\bar{h}_c A)_{cold}}$

FIGURE 7.4 Heat transfer from a hot gas to a cold gas through a plane wall.

where:

$$\theta_1 = \frac{1}{(\bar{h}_c A)_{hot}}$$

$$\theta_2 = \frac{L}{kA}$$

$$\theta_3 = \frac{1}{(\bar{h}_c A)_{cold}}$$

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You can easily find out, how these things work ok.

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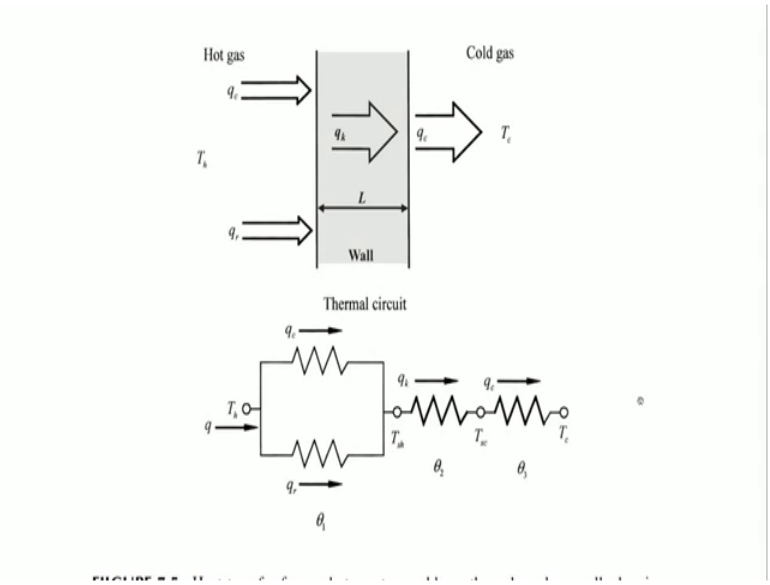

So, and then you have several parallel paths, hot gas to a cold gas, through a plane wall showing a parallel path for radiation seen that. Now, the moment something is what you have a little chance of a radiation also going through.

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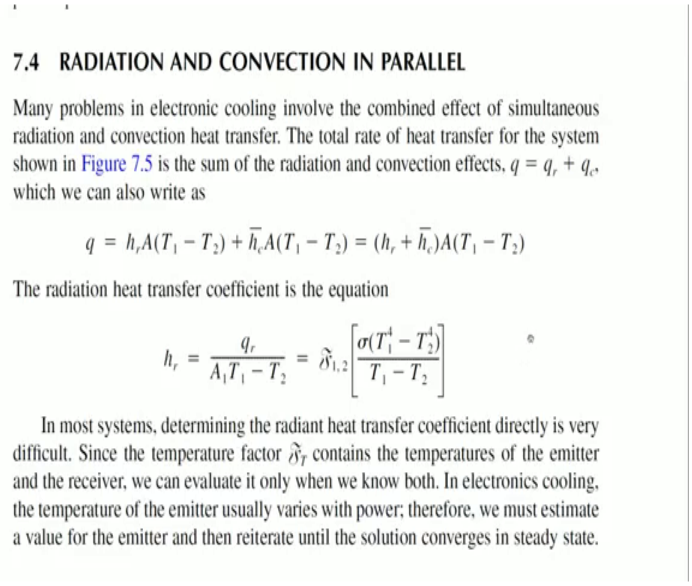

7.4 RADIATION AND CONVECTION IN PARALLEL

Many problems in electronic cooling involve the combined effect of simultaneous radiation and convection heat transfer. The total rate of heat transfer for the system shown in Figure 7.5 is the sum of the radiation and convection effects, $q = q_r + q_c$, which we can also write as

$$q = h_r A(T_1 - T_2) + \bar{h}_c A(T_1 - T_2) = (h_r + \bar{h}_c)A(T_1 - T_2)$$

The radiation heat transfer coefficient is the equation

$$h_r = \frac{q_r}{A_1 T_1 - T_2} = \mathscr{F}_{1,2}\left[\frac{\sigma(T_1^4 - T_2^4)}{T_1 - T_2}\right]$$

In most systems, determining the radiant heat transfer coefficient directly is very difficult. Since the temperature factor $\mathscr{F}_T$ contains the temperatures of the emitter and the receiver, we can evaluate it only when we know both. In electronics cooling, the temperature of the emitter usually varies with power; therefore, we must estimate a value for the emitter and then reiterate until the solution converges in steady state.

So, you can have radiation and convection in parallel. So, since is a matter of equations again, it is more like handbook material, you probably need to get back with your specific case try. To work on these thing, we come to the final overall thing saying the combined simultaneous, radiation convection total area of heat transfer and so on. Eventually, overall heat transfer coefficient, overall coefficient is used to describe.

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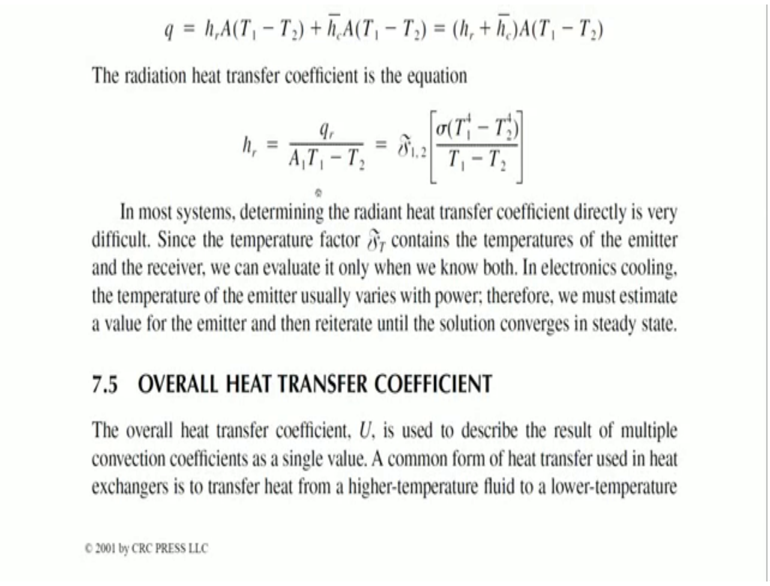

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The radiation heat transfer coefficient is the equation

$$h_r = \frac{q_r}{A_1 T_1 - T_2} = \tilde{\mathfrak{F}}_{1,2}\left[\frac{\sigma(T_1^4 - T_2^4)}{T_1 - T_2}\right]$$

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7.5 OVERALL HEAT TRANSFER COEFFICIENT

The overall heat transfer coefficient, U, is used to describe the result of multiple convection coefficients as a single value. A common form of heat transfer used in heat exchangers is to transfer heat from a higher-temperature fluid to a lower-temperature

The result of multiple convection coefficients as a single value; Common form of heat transfer used in exchangers is to transfer heat from a.

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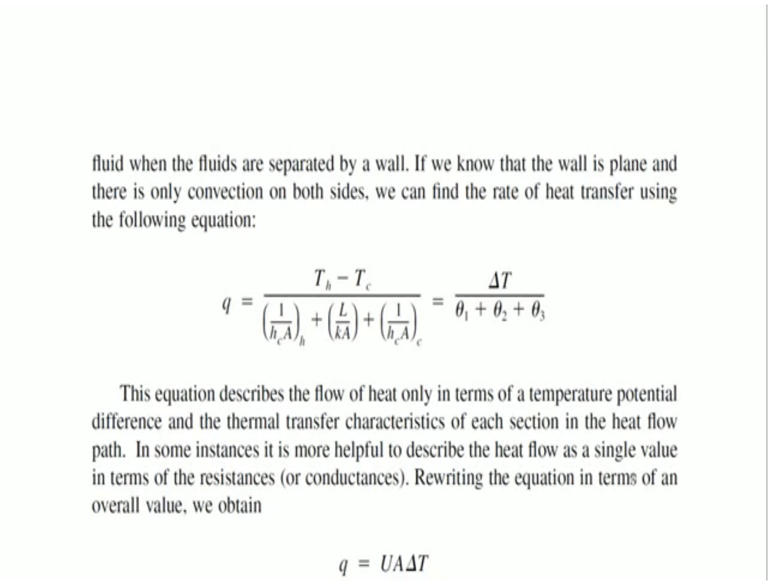

fluid when the fluids are separated by a wall. If we know that the wall is plane and there is only convection on both sides, we can find the rate of heat transfer using the following equation:

$$q = \frac{T_h - T_c}{\left(\frac{1}{h_c A}\right)_h + \left(\frac{L}{kA}\right) + \left(\frac{1}{h_c A}\right)_c} = \frac{\Delta T}{\theta_1 + \theta_2 + \theta_3}$$

This equation describes the flow of heat only in terms of a temperature potential difference and the thermal transfer characteristics of each section in the heat flow path. In some instances it is more helpful to describe the heat flow as a single value in terms of the resistances (or conductances). Rewriting the equation in terms of an overall value, we obtain

$$q = UA\Delta T$$

Fluid with higher temperature to lower and the fluids are separated by all, if you know that the wall is plane and there is only convection on both sides, we can find the rate. These are all very routine things, everywhere. Now, end of the delta T and this status.

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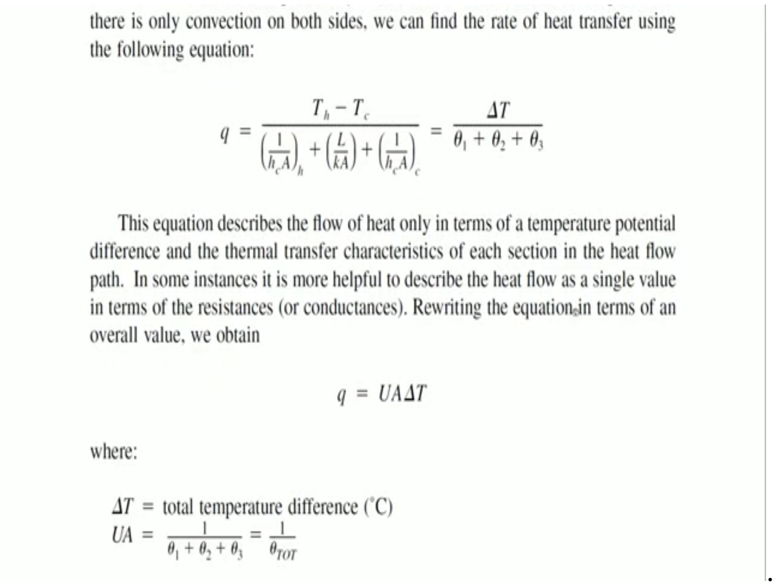

there is only convection on both sides, we can find the rate of heat transfer using the following equation:

$$q = \frac{T_h - T_c}{\left(\frac{1}{h_c A}\right)_h + \left(\frac{L}{kA}\right) + \left(\frac{1}{h_c A}\right)_c} = \frac{\Delta T}{\theta_1 + \theta_2 + \theta_3}$$

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$$q = UA\Delta T$$

where:

ΔT = total temperature difference (°C)

$UA = \frac{1}{\theta_1 + \theta_2 + \theta_3} = \frac{1}{\theta_{TOT}}$

Describe the flow heat only in terms of the temperature potential and transfer of each section of the heat flow of path.

Some instance says, it may be helpful to describe the heat flow single value in terms of resistances, rewriting the equations gives directly delta temperature area.

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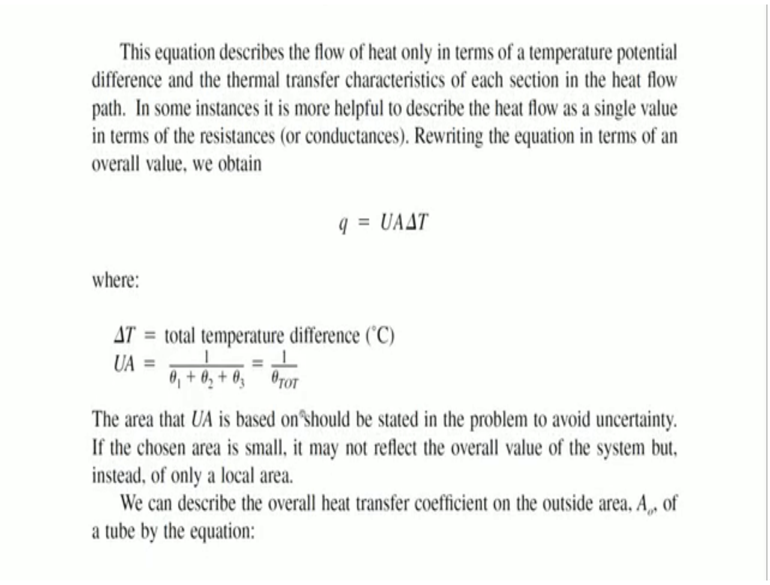

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$$q = UA\Delta T$$

where:

ΔT = total temperature difference (°C)

$UA = \frac{1}{\theta_1 + \theta_2 + \theta_3} = \frac{1}{\theta_{TOT}}$

The area that UA is based on should be stated in the problem to avoid uncertainty. If the chosen area is small, it may not reflect the overall value of the system but, instead, of only a local area.

We can describe the overall heat transfer coefficient on the outside area, A_o, of a tube by the equation:

And U area UA is based should be stated in the problem to avoid uncertainty, if the chosen area is small, it may not reflect the overall value instead of a local value, you can describe the overall heat transfer coefficient on the outside area a 0 of a tube by equation.

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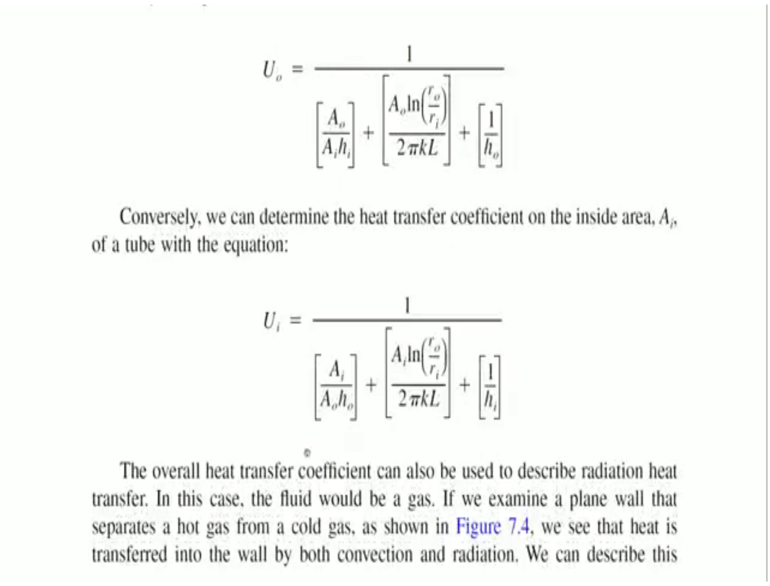

$$U_o = \frac{1}{\left[\frac{A_o}{A_i h_i}\right] + \left[\frac{A_o \ln\left(\frac{r_o}{r_i}\right)}{2\pi k L}\right] + \left[\frac{1}{h_o}\right]}$$

Conversely, we can determine the heat transfer coefficient on the inside area, A_i, of a tube with the equation:

$$U_i = \frac{1}{\left[\frac{A_i}{A_o h_o}\right] + \left[\frac{A_i \ln\left(\frac{r_o}{r_i}\right)}{2\pi k L}\right] + \left[\frac{1}{h_i}\right]}$$

The overall heat transfer coefficient can also be used to describe radiation heat transfer. In this case, the fluid would be a gas. If we examine a plane wall that separates a hot gas from a cold gas, as shown in Figure 7.4, we see that heat is transferred into the wall by both convection and radiation. We can describe this

So, these things go on and on and on and on and on ok.

So, it is for you since, it is a handbook type material. We have several tables here, which describe from the appendix ok. So, many of these, many things are mentioned here in the appendix saying as a huge appendix, which is you know, which gives data relating to most values, which are likely to face.

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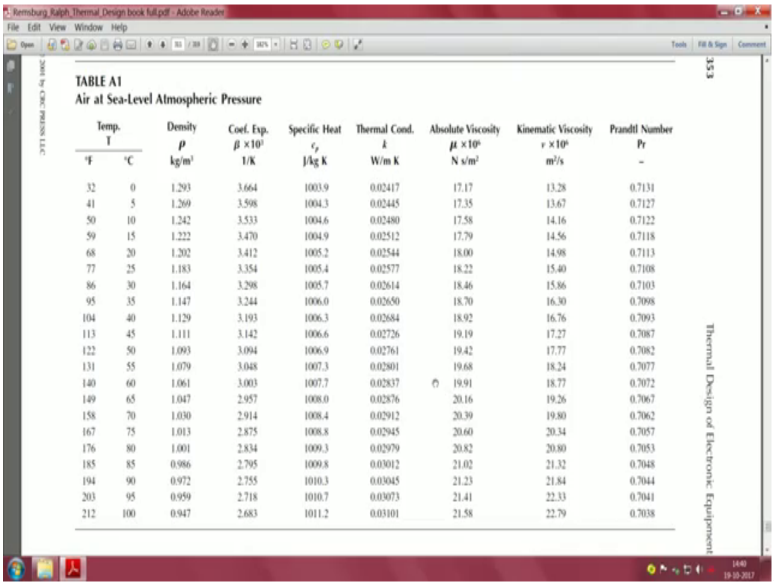

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TABLE A1
Air at Sea-Level Atmospheric Pressure

Temp. T °F	Temp. T °C	Density ρ kg/m³	Coef. Exp. $\beta \times 10^3$ 1/K	Specific Heat c_p J/kg K	Thermal Cond. k W/m K	Absolute Viscosity $\mu \times 10^6$ N s/m²	Kinematic Viscosity $\nu \times 10^6$ m²/s	Prandtl Number Pr –
32	0	1.293	3.664	1003.9	0.02417	17.17	13.28	0.7131
41	5	1.269	3.598	1004.3	0.02445	17.35	13.67	0.7127
50	10	1.242	3.533	1004.6	0.02480	17.58	14.16	0.7122
59	15	1.222	3.470	1004.9	0.02512	17.79	14.56	0.7118
68	20	1.202	3.412	1005.2	0.02544	18.00	14.98	0.7113
77	25	1.183	3.354	1005.4	0.02577	18.22	15.40	0.7108
86	30	1.164	3.298	1005.7	0.02614	18.46	15.86	0.7103
95	35	1.147	3.244	1006.0	0.02650	18.70	16.30	0.7098
104	40	1.129	3.193	1006.3	0.02684	18.92	16.76	0.7093
113	45	1.111	3.142	1006.6	0.02726	19.19	17.27	0.7087
122	50	1.093	3.094	1006.9	0.02761	19.42	17.77	0.7082
131	55	1.079	3.048	1007.3	0.02801	19.68	18.24	0.7077
140	60	1.061	3.003	1007.7	0.02837	19.91	18.77	0.7072
149	65	1.047	2.957	1008.0	0.02876	20.16	19.26	0.7067
158	70	1.030	2.914	1008.4	0.02912	20.39	19.80	0.7062
167	75	1.013	2.875	1008.8	0.02945	20.60	20.34	0.7057
176	80	1.001	2.834	1009.3	0.02979	20.82	20.80	0.7053
185	85	0.986	2.795	1009.8	0.03012	21.02	21.32	0.7048
194	90	0.972	2.755	1010.3	0.03045	21.23	21.84	0.7044
203	95	0.959	2.718	1010.7	0.03073	21.41	22.33	0.7041
212	100	0.947	2.683	1011.2	0.03101	21.58	22.79	0.7038

Thermal Design of Electronic Equipment

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Air at sea level atmospheric pressure; so, we have thermal conductivity and Kinematic Viscosity, similarly, water at sea level. So, again you have thermal conductivity and then you have, perflurocarbons, which are you know part of the preservation system.

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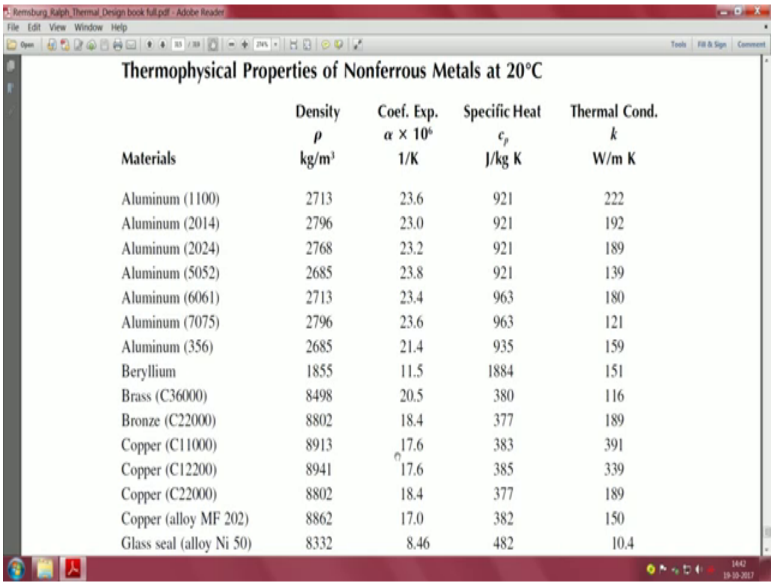

Thermophysical Properties of Nonferrous Metals at 20°C

Materials	Density ρ kg/m³	Coef. Exp. $\alpha \times 10^6$ 1/K	Specific Heat c_p J/kg K	Thermal Cond. k W/m K
Aluminum (1100)	2713	23.6	921	222
Aluminum (2014)	2796	23.0	921	192
Aluminum (2024)	2768	23.2	921	189
Aluminum (5052)	2685	23.8	921	139
Aluminum (6061)	2713	23.4	963	180
Aluminum (7075)	2796	23.6	963	121
Aluminum (356)	2685	21.4	935	159
Beryllium	1855	11.5	1884	151
Brass (C36000)	8498	20.5	380	116
Bronze (C22000)	8802	18.4	377	189
Copper (C11000)	8913	17.6	383	391
Copper (C12200)	8941	17.6	385	339
Copper (C22000)	8802	18.4	377	189
Copper (alloy MF 202)	8862	17.0	382	150
Glass seal (alloy Ni 50)	8332	8.46	482	10.4

So, many of these correlation and thing and about the K and these parameters, which have been used in the earlier equations are listed out in the, in this appendix. So, you see here very commonly, we have these 60 and 70 series aluminium, which are made meant for hard strong.

So, you can say your, what you call performance bicycles, occasionally you have these, what you call aircraft things and all that you know, they all form under this 5 and 5000, 6000 and 7000 series things here, but one thing the compromise seems to be basic thermal conductivity is the soft-soft simple, what we call aluminium and this could be vary ends with more and more zinc and, what we call silicon and magnesium and zinc combinations.

So, I will, I am sorry silicon and magnesium combinations with aluminium as you improve the things here, they very hard ones, have a conductivity is only a half of the soft aluminium. Similarly, we come with various types of brass and bronze and copper here, you have seen this things like this, see 1 to 2 0 0 and all that they form under the category called FRHC fire refined high conductivity copper. Next time, got a chance open another pentium or the main CPO chip in a computer.

I am sure you have enough electronic e based computers, you open it and then you will find the fan underneath, you find the heat spreader and if you turn it up's and down, sometimes in the heat spreader you will see the material and the centre has been bought out and the core of copper has been pushed inside. Why? That is required is aluminium itself and the way it is configured is not able to take away heat at the rate, at which we want the conduction to improve, unless the whole system will fail and unless you have the highest conductivity of copper.

So, copper like this these coppers are used very-very pure copper materials. There the start with very-very soft and then you see conductivity is very-very high, then if you go down, you find things, which will like and of course, gold you cannot afford it except in the case of a few, what they say may be where corrosion also is important and things should not be degrade, electrical conductivity should not degrade with corrosion that places. Gold are used, but very thin layers may be sub-micron layers.

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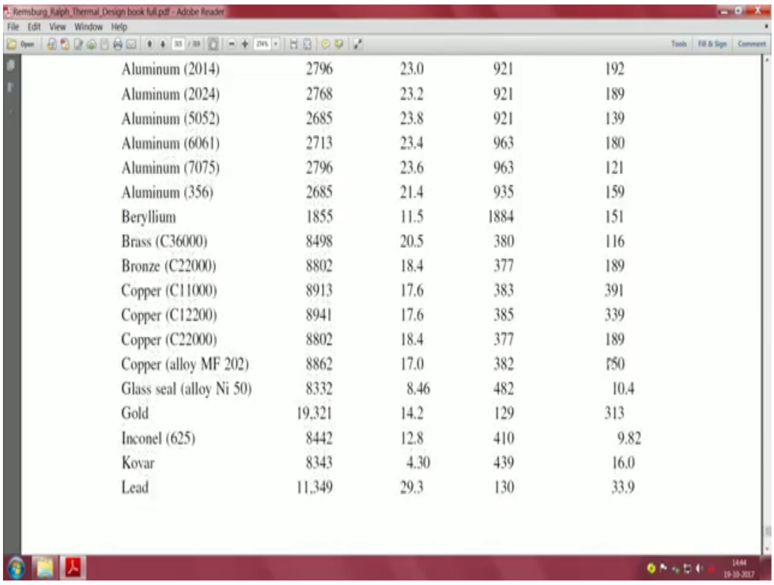

Aluminum (2014)	2796	23.0	921	192
Aluminum (2024)	2768	23.2	921	189
Aluminum (5052)	2685	23.8	921	139
Aluminum (6061)	2713	23.4	963	180
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Copper (C22000)	8802	18.4	377	189
Copper (alloy MF 202)	8862	17.0	382	150
Glass seal (alloy Ni 50)	8332	8.46	482	10.4
Gold	19,321	14.2	129	313
Inconel (625)	8442	12.8	410	9.82
Kovar	8343	4.30	439	16.0
Lead	11,349	29.3	130	33.9

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So, as we go down you notice that we still cannot beat copper. So, as we go down, we have all these interesting, very-very interesting materials rather material properties, which probably come across.

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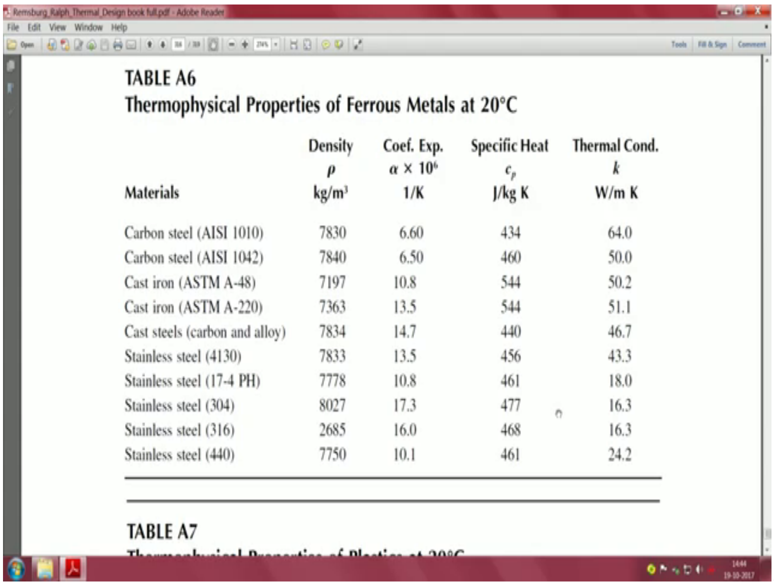

TABLE A6
Thermophysical Properties of Ferrous Metals at 20°C

Materials	Density ρ kg/m³	Coef. Exp. $\alpha \times 10^6$ 1/K	Specific Heat c_p J/kg K	Thermal Cond. k W/m K
Carbon steel (AISI 1010)	7830	6.60	434	64.0
Carbon steel (AISI 1042)	7840	6.50	460	50.0
Cast iron (ASTM A-48)	7197	10.8	544	50.2
Cast iron (ASTM A-220)	7363	13.5	544	51.1
Cast steels (carbon and alloy)	7834	14.7	440	46.7
Stainless steel (4130)	7833	13.5	456	43.3
Stainless steel (17-4 PH)	7778	10.8	461	18.0
Stainless steel (304)	8027	17.3	477	16.3
Stainless steel (316)	2685	16.0	468	16.3
Stainless steel (440)	7750	10.1	461	24.2

TABLE A7

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Now, we come to the little what we call, I will see. You know well, I will not say it is a sad part, it is a reality part, reality part is what we commonly call sheet metal is there to stay. So, sheet metal usually comes as this carbon steels, mild carbon steel. So, the main advantage of it is the overall price is low, easy availability and, because of it is inherent toughness. It gives a pleasant appearance and does not get dented easily, which is the and in a given thickness and weight even today, it is a good choice, that is a reason your cars, car panels continue to be made with simple m baster formed sheets, sheet metal, it is often zinc plated ok.

So, in the, in the role form itself and zinc plate after that fabrication is easy and one more thing related is all sets of operations can be done easily and finally, eventually even painting is easy, painting various types of electroplating and so on are easy in ferrous materials. This is, where we end up with whether you like it or not this carbon steels, you know continue to be used very close to, it is cast iron. Cast iron is used in some special conditions, but in this case, we are not talking about direct application as much as, we are talking about the thermal properties of it, if you go here, you see that basic stainless steel and all that you know, there quite good in it.

But then I am sure several offers have come across 304 stainless steel, which is again commonly used the advantage of this 304, is that, is the one, you use, you see everywhere. You see everywhere, all the, all the shining things, you see probably dining stuff and all that know comes with some variants of these things.

So, the advantage is that it is not affected by atmosphere and it does give a slightly good, you know appearance to it, then the disadvantages. Heat conductivity is low and sometimes these are also used as spring materials. So, this what you call appendix, does not have the spring material. So, characteristic. So, if you see your battery contact or if you see any of your things inside a connector, they are not generally made with this, but if you take a spring, have your usual double, a cells and you have a spring at the back.

So, it is nothing, but it is a drawn wire, probably piano wire, 0.9 to 1.2 millimetres diameter and it has to carry current and occasionally, it has to carry heat. This is where your problem comes, added to that we have a problem of dissimilar metals, which is probably the reason why most of your portable equipment, if you are what you call, TV remote does not work, what you do? You bang it or open the back and then try to roll the batteries and you know take it and rub it and all that.

The issue is the moment you have a dissimilar metals, it will form a, electrochemical cell, which will lead to so many other problems. So, the, but the main problem is you still have thermal conductivity is slow.

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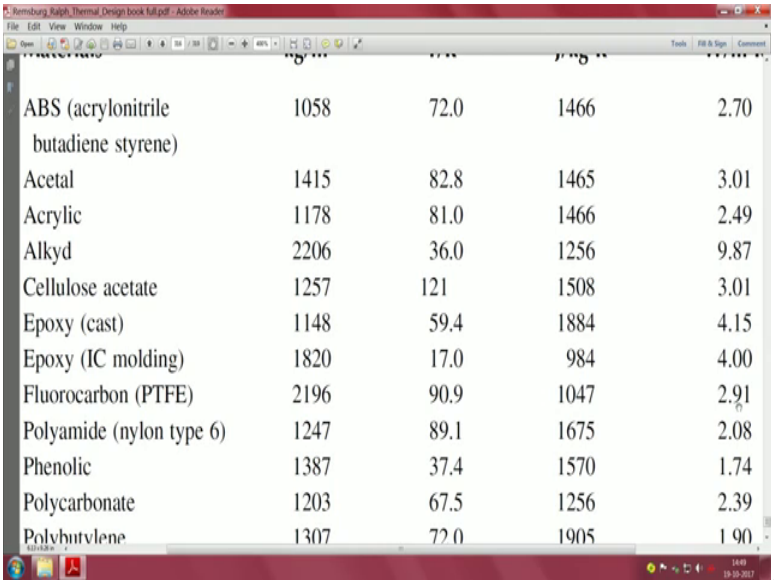

ABS (acrylonitrile butadiene styrene)	1058	72.0	1466	2.70
Acetal	1415	82.8	1465	3.01
Acrylic	1178	81.0	1466	2.49
Alkyd	2206	36.0	1256	9.87
Cellulose acetate	1257	121	1508	3.01
Epoxy (cast)	1148	59.4	1884	4.15
Epoxy (IC molding)	1820	17.0	984	4.00
Fluorocarbon (PTFE)	2196	90.9	1047	2.91
Polyamide (nylon type 6)	1247	89.1	1675	2.08
Phenolic	1387	37.4	1570	1.74
Polycarbonate	1203	67.5	1256	2.39
Polybutylene	1307	72.0	1905	1.90

So, you have various, you know properties people play with, while that is well known, what is not known at all about is the thermal properties of plastics as of today, unless you actually apply it or make an experiment, this last figures you know are only indicative, because all the time big companies like BSF (Refer Time: 26:47) are all the, what you call people who work on plastics, they keep formulating and making new things.

So, there is a thing call, you know ABS, we also have called nylon ABS same, similar types of materials are used in your normal commercial equipment as well as a bumper in your car, but; obviously, the car bumper has very good fantastic physical properties. So, not only it is impact, it's gives you a controlled crushing, which will take care of the what you call various crushed test and all that.

Now, coming back to our thermal aspects of thing you have, this is a Acetal copolymer. So, many of these thing there, all very special things, acrylic is all your windows, whether you like it or not, your what you call poly glass and Romandos? What you call Plexiglas? All of them are acrylic, then you have cellulose acetate, all these things, you know problem is the conductivity is not very good it is real.

So, how do you take care of it, sometimes it is desirable as in the case of our switches and so on. So, the switch does not feel hot when you press, you may even feel sparks and all coming, but it does not get what the domestic households switch, it has to take away heat likely inside the actual sheet, carrying elements are probably brass and the contact point is probably brass, which is coated with silver and so on and so on.

So, the combination of these things, heat has to be transmitted in spite of our, you know best effort, when at starts switches will not be giving any heat in due course, the slowly develop a small resistance with high current, heat is developed same. It is in the case of our things like transformers, which we think are passive actually, they are generating a lot of heat, they are active in generating heat.

So, we come to these things like epoxy IC moulding, epoxy will not have been lovely, if we had a proper conductive epoxy, thermally conducting and electrically insulating people are working on it. I do not know whether they are still, they are using heat or not, at those cases while it is you say, I am wearing this fancy watch, I am sure some of you will know what this fancy watches?

It has fantastic properties like, it has a magnetic property and then there is a some plate rubber, question here and when I remove it, see the way whole thing is actually stainless steel strap. I do not know how they have done when I say stainless steel, it does not stain thing is, it is still magnetic. So, I will notice is, martensitic, you know generally magnetite magnetic austenitic steel is not magnetic, you see this and more than this the wonder comes at the bottom ok.

I have a sensor here, there is a sensor in the middle, there 2 led's, something is blinking and it is actually you know something very-very active and it is a wonder and you know, you can charge it and the whole thing is does not cost anything, the original, I think I got it gifted and it cost around 15,000 rupees that may be around 200 US dollars and the clown is available for 1000 rupees 999 and which is nothing, but 15 dollars, that is the lot of this thing and you see that, this is expected, I expect that you know I will carry to the grave with me, not that I hope to pusses soon, but then it is going to last a long time and then usually waterproof and splash proof and all that.

Now, you see here, the really good ones have no choice, but to make it in metals and only a small layers, small see, even whole cases, here is metallic only, only the critical portion, they have made it out of plastic, they make it out of plastic, all that series metal combinations are important.

You see here, typically these things are used, then we have the another, what is taken as a wonder material, we have two things polycarbonate and polypropylene. Now, everything you see polycarbonate has advantage of that is a little transparent things like, your blender jars, things like your other things, you know are all made with polycarbonate, but very peculiarly, it is scratch prone acrylic gives you a nice smooth surface, but it has other issues with it.

So, probably need to consider more and more things like this. So, we have polyethylene, this is the stuff of which are plastic buckets and mugs and all are made, then we have poly propylene. PVC is the material by default, wherever you go, you have PVC stuff, we next come to thermo fiscal properties or ceramics. I am not very, how do you say I belong to the old school, I have really no idea, how the ceramics are used, except the toils like you have been reading about it.

Soil avoid except to say that we have fantastic, you see here, cubic boron nitride seems to be having tremendous amount of thermal conductivity much better than aluminium, copper and those things 6 times that of aluminium and may be you know 4 times that of copper, which is very good almost as good as film diamond, then we have the other things, I do not know, they would not given the silicon and silicon carbide, this is a little, how do you say, do not know. How to use these information, but still in the case of gas, the temperature you know, conductivity; I am sorry, coefficient and so on are all given here, very rarely I mean.

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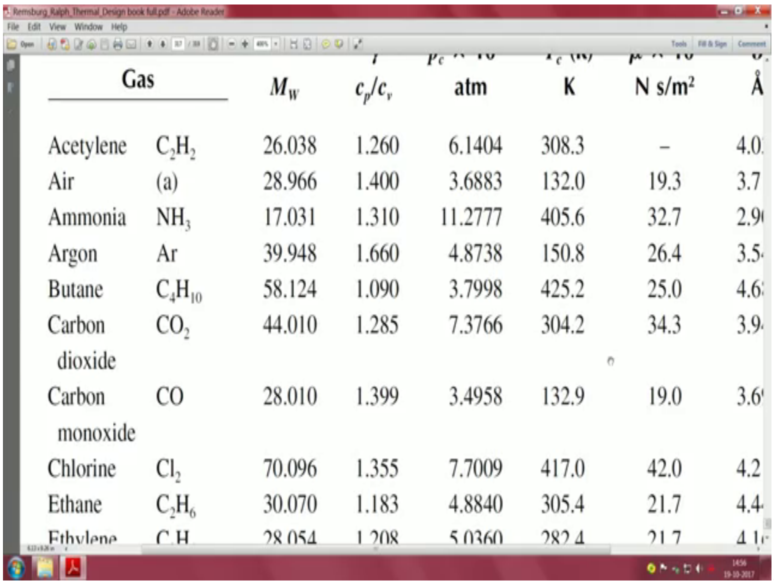

Gas		M_W	c_p/c_v	atm	K	N s/m²	Å
Acetylene	C_2H_2	26.038	1.260	6.1404	308.3	–	4.0
Air	(a)	28.966	1.400	3.6883	132.0	19.3	3.7
Ammonia	NH_3	17.031	1.310	11.2777	405.6	32.7	2.9
Argon	Ar	39.948	1.660	4.8738	150.8	26.4	3.5
Butane	C_4H_{10}	58.124	1.090	3.7998	425.2	25.0	4.6
Carbon dioxide	CO_2	44.010	1.285	7.3766	304.2	34.3	3.9
Carbon monoxide	CO	28.010	1.399	3.4958	132.9	19.0	3.6
Chlorine	Cl_2	70.096	1.355	7.7009	417.0	42.0	4.2
Ethane	C_2H_6	30.070	1.183	4.8840	305.4	21.7	4.4
Ethylene	C H	28.054	1.208	5.0360	282.4	21.7	4.1

It is used only as a mass flow rate. So, I have no, I have no experience in interpreting all these things except that, is a textbook information inside, if you see reference has been made to these things.

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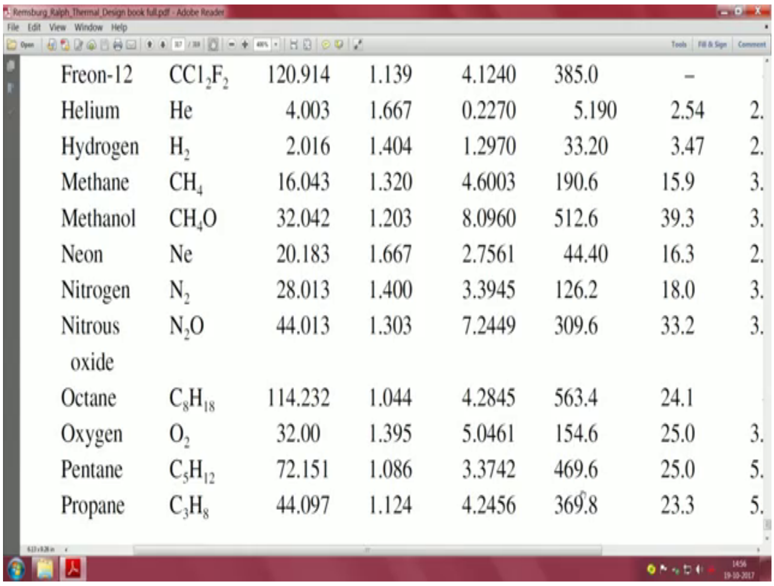

Freon-12	$CC1_2F_2$	120.914	1.139	4.1240	385.0	–	
Helium	He	4.003	1.667	0.2270	5.190	2.54	2.
Hydrogen	H_2	2.016	1.404	1.2970	33.20	3.47	2.
Methane	CH_4	16.043	1.320	4.6003	190.6	15.9	3.
Methanol	CH_4O	32.042	1.203	8.0960	512.6	39.3	3.
Neon	Ne	20.183	1.667	2.7561	44.40	16.3	2.
Nitrogen	N_2	28.013	1.400	3.3945	126.2	18.0	3.
Nitrous oxide	N_2O	44.013	1.303	7.2449	309.6	33.2	3.
Octane	C_8H_{18}	114.232	1.044	4.2845	563.4	24.1	
Oxygen	O_2	32.00	1.395	5.0461	154.6	25.0	3.
Pentane	C_5H_{12}	72.151	1.086	3.3742	469.6	25.0	5.
Propane	C_3H_8	44.097	1.124	4.2456	369.8	23.3	5.

So, common things say probably, you have hydrogen, then you have common air, then of course, this nitrous oxide.

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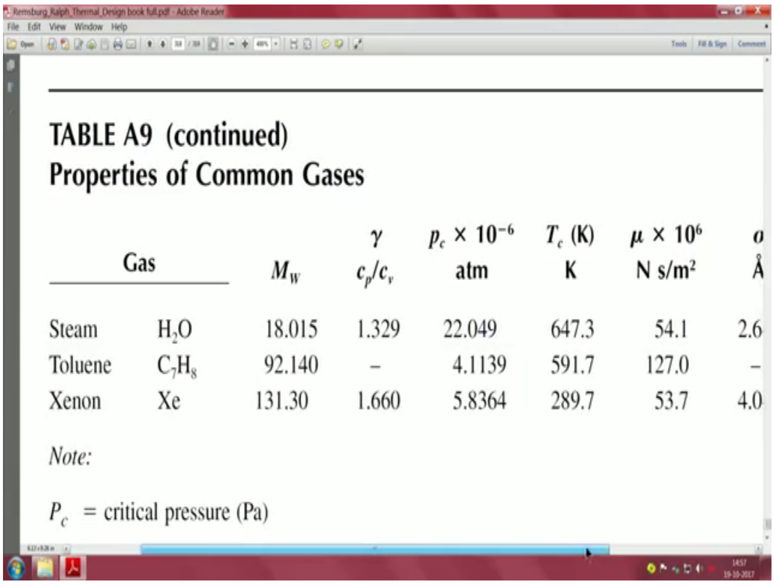

TABLE A9 (continued)
Properties of Common Gases

Gas		M_W	γ c_p/c_v	$p_c \times 10^{-6}$ atm	T_c (K) K	$\mu \times 10^6$ N s/m²	σ Å
Steam	H_2O	18.015	1.329	22.049	647.3	54.1	2.6
Toluene	C_7H_8	92.140	–	4.1139	591.7	127.0	–
Xenon	Xe	131.30	1.660	5.8364	289.7	53.7	4.0

Note:

P_c = critical pressure (Pa)

So, you have so many of these parameters, related to this. I will glass over these things, because I have no idea about these various things, some other time you work it out.

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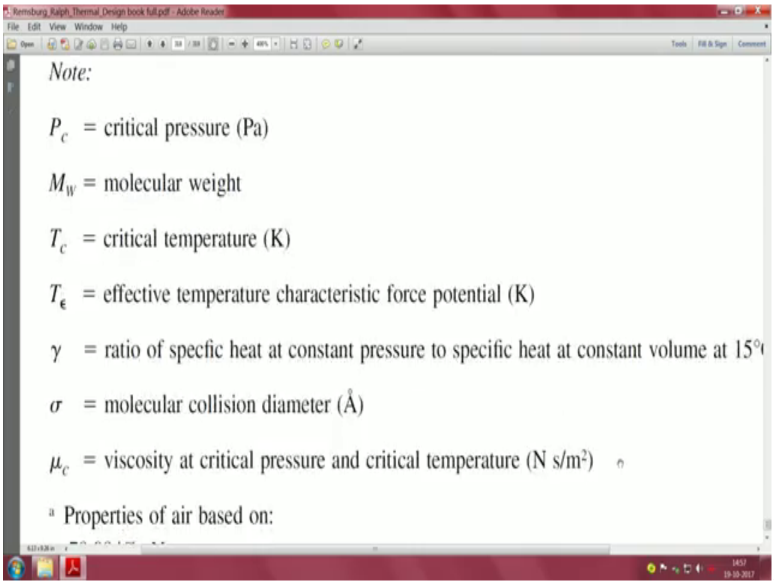

Note:

P_c = critical pressure (Pa)

M_W = molecular weight

T_c = critical temperature (K)

T_ϵ = effective temperature characteristic force potential (K)

γ = ratio of specfic heat at constant pressure to specific heat at constant volume at 15°

σ = molecular collision diameter (Å)

μ_c = viscosity at critical pressure and critical temperature (N s/m²)

[a] Properties of air based on:

So, we have this stuff about critical temperatures, effective temperatures characteristic; force potential specific heat at constant pressure to specific heat and so on.

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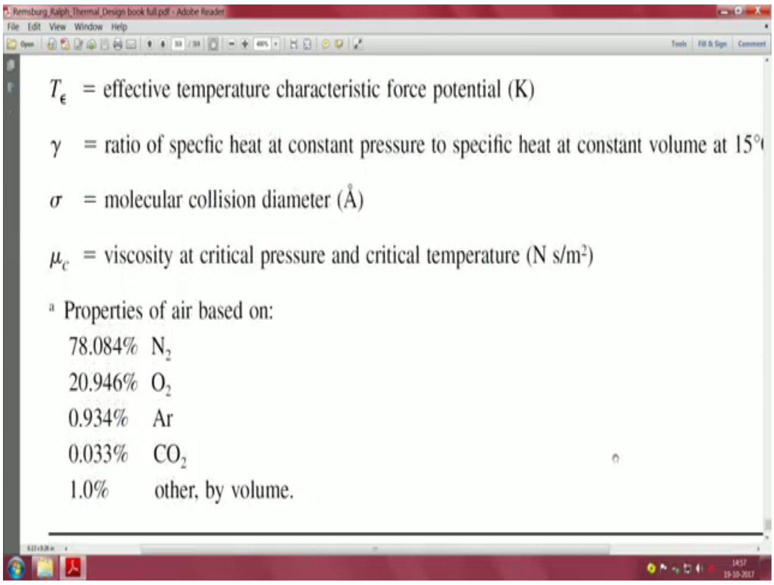

T_ϵ = effective temperature characteristic force potential (K)

γ = ratio of specfic heat at constant pressure to specific heat at constant volume at 15°

σ = molecular collision diameter (Å)

μ_c = viscosity at critical pressure and critical temperature (N s/m^2)

[a] Properties of air based on:

78.084%	N_2
20.946%	O_2
0.934%	Ar
0.033%	CO_2
1.0%	other, by volume.

You can, you know air is based on combinations of these things.

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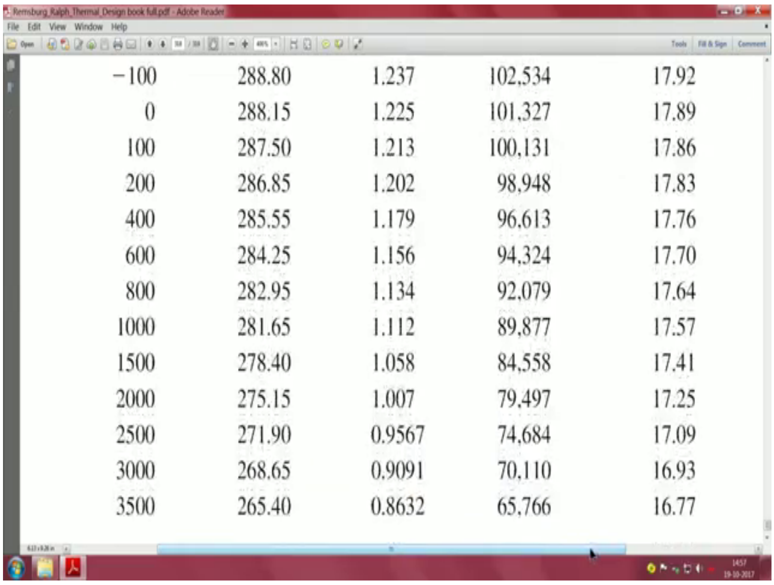

−100	288.80	1.237	102,534	17.92
0	288.15	1.225	101,327	17.89
100	287.50	1.213	100,131	17.86
200	286.85	1.202	98,948	17.83
400	285.55	1.179	96,613	17.76
600	284.25	1.156	94,324	17.70
800	282.95	1.134	92,079	17.64
1000	281.65	1.112	89,877	17.57
1500	278.40	1.058	84,558	17.41
2000	275.15	1.007	79,497	17.25
2500	271.90	0.9567	74,684	17.09
3000	268.65	0.9091	70,110	16.93
3500	265.40	0.8632	65,766	16.77

So, this is probably the end of the; this appendix and the end of this thing, what I wanted to talk about next lecture, I would like to talk about the Peltier element design guide.

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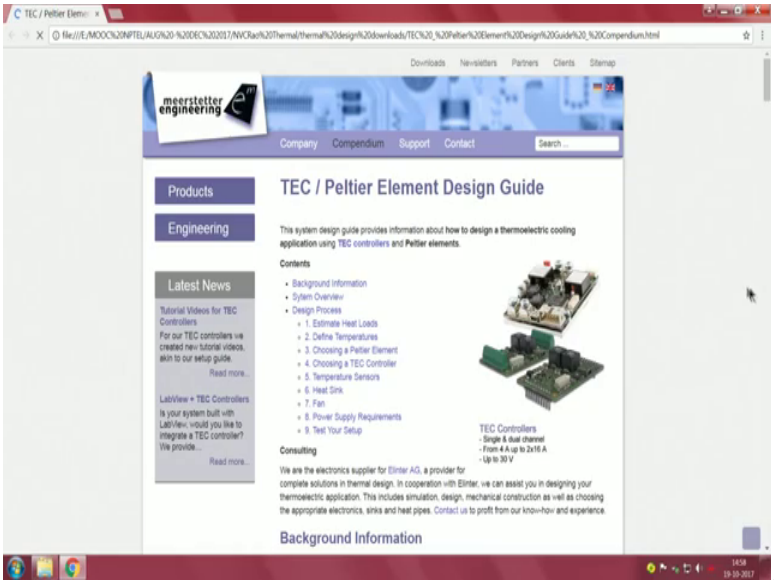

Tutorial Videos for TEC Controllers
For our TEC controllers we created new tutorial videos, akin to our setup guide.

LabView + TEC Controllers
Is your system built with LabView, would you like to integrate a TEC controller? We provide...

TEC / Peltier Element Design Guide

This system design guide provides information about **how to design a thermoelectric cooling application** using TEC controllers and **Peltier elements**.

Contents

- Background Information
- Sytem Overview
- Design Process
  - 1. Estimate Heat Loads
  - 2. Define Temperatures
  - 3. Choosing a Peltier Element
  - 4. Choosing a TEC Controller
  - 5. Temperature Sensors
  - 6. Heat Sink
  - 7. Fan
  - 8. Power Supply Requirements
  - 9. Test Your Setup

TEC Controllers
- Single & dual channel
- From 4 A up to 2x16 A
- Up to 30 V

Consulting

We are the electronics supplier for Elinter AG, a provider for complete solutions in thermal design. In cooperation with Elinter, we can assist you in designing your thermoelectric application. This includes simulation, design, mechanical construction as well as choosing the appropriate electronics, sinks and heat pipes. Contact us to profit from our know-how and experience.

Background Information

Once again it is taken from Meerstetter. Meerstetter has a huge collection of, stuff about Peltier element design guide saying, how to estimate the heat loads? How to choose a Peltier element? To me its looks like a novelty item, but not necessarily the practical item.

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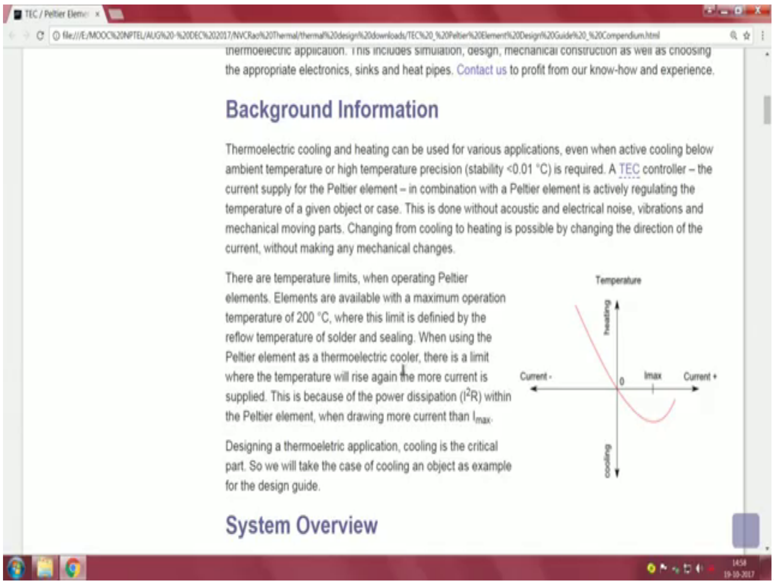

thermoelectric application. This includes simulation, design, mechanical construction as well as choosing the appropriate electronics, sinks and heat pipes. Contact us to profit from our know-how and experience.

Background Information

Thermoelectric cooling and heating can be used for various applications, even when active cooling below ambient temperature or high temperature precision (stability <0.01 °C) is required. A TEC controller – the current supply for the Peltier element – in combination with a Peltier element is actively regulating the temperature of a given object or case. This is done without acoustic and electrical noise, vibrations and mechanical moving parts. Changing from cooling to heating is possible by changing the direction of the current, without making any mechanical changes.

There are temperature limits, when operating Peltier elements. Elements are available with a maximum operation temperature of 200 °C, where this limit is definied by the reflow temperature of solder and sealing. When using the Peltier element as a thermoelectric cooler, there is a limit where the temperature will rise again the more current is supplied. This is because of the power dissipation (I^2R) within the Peltier element, when drawing more current than I_{max}.

Designing a thermoeletric application, cooling is the critical part. So we will take the case of cooling an object as example for the design guide.

System Overview

So, I will stop this session here and next session, which I talk, I will exclusively talk about these devices with Peltier cooling, based on system or saying whatever it is so.

Thank you.