Fundamentals of Electric Vehicles
Technology & Economics
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Lecture 09
Thermal Design - Part 4

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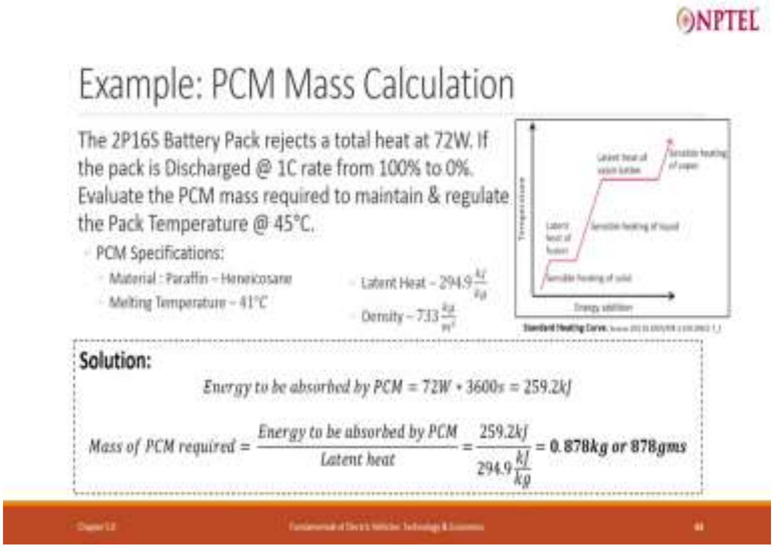

Now a example problem, since PCM is quite, it is used at many of the places for passive thermal management system especially in battery, so let us calculate what would be the (())(00:41) in material amount required? Now in a same battery pack, 2P16S, what is our heat rejection or total heat? 72 watts at 1C discharge. Now, if pack is discharge at 1C rate from 100 percent to 0 percent, evaluate the PCM mass required to maintain and regulate the pack temperature at 45 degree C.

The PCM specification has been given. Material: Paraffin, melting temperature is approximately 41 degree C. When I say 41 degree C, generally it works out in 3 to 4 degree centigrade, 3 to 4 degree range and that happens because of the thermal conductivity. It is a way it generally has very less thermal conductivity. So, it is takes, by the time my first layer gets heated up to 41, it gets melted. My second layer is 41, it start melting but this layer temperature start increasing by 42, 43, but very small temperature in.

So, now what is the total (led) what is the latent heat of this? It is 294.9 kilojoule per kg of this PCM. The density of the PCM is 733 kg per metre cube. It is lighter than water. Now, what is the energy absorbed by PCM? What energy has to be absorbed by PCM? 72 watts into 3600 seconds because once it discharged would come to 1 hour. So, 259.2 kilojoule 259.2 kilojoule energy has to be absorbed by PCM. 1 kg PCM how much energy it can absorb, that is nothing but it is latent heat is 294.9 kilojoule.

So, what is the mass of PCM required; 259.2 divided by 294.9 is approximately 900 gram. What we have seen there in the battery pack, what was my weight of battery pack? Cell was around 11 kg. What is the, what was the percentage heat released as a heat from it; 100 to 20 percent or on 4 percent? So, 100 to 0 percent it will be around 5 percent, 5, 5 and half percent. How much weight we are increasing? Approximately 7 percent, 7 to 8 percent because the cell weight was only 11 kg there is other mechanical bus bars, plates, outer casing, it would come around 13 kg, 12 and half, 13 kg.

How much weight we are adding? Around 900 gram and then we can keep the battery pack always 45 or below because a maximum ambient temperature would be generally 45. We will show you the some stimulations and test results later that if I do not put this one might the battery pack temperature at once discharge can go in 45 ambient to 65. So, I am still able to maintain my pack to 45, 46 around 20 degree difference. I might not be able to get the same cycles what I would have got between 15 to 35.

Let suppose it is 1200 cycles, but at 65 it would have been 300, 350 cycles or 400 cycles. At 45, I can still get 1000 cycle without putting active thermal management system. So, that is the beauty of passive thermal management system. I do not get what I exactly supposed to get, I tried of slightly, but still I try to get the maximum out of it. So this, what we have discussed till now was mostly the active and passive thermal management system. Now we will talk about what are the materials and design generally we use in thermal design.

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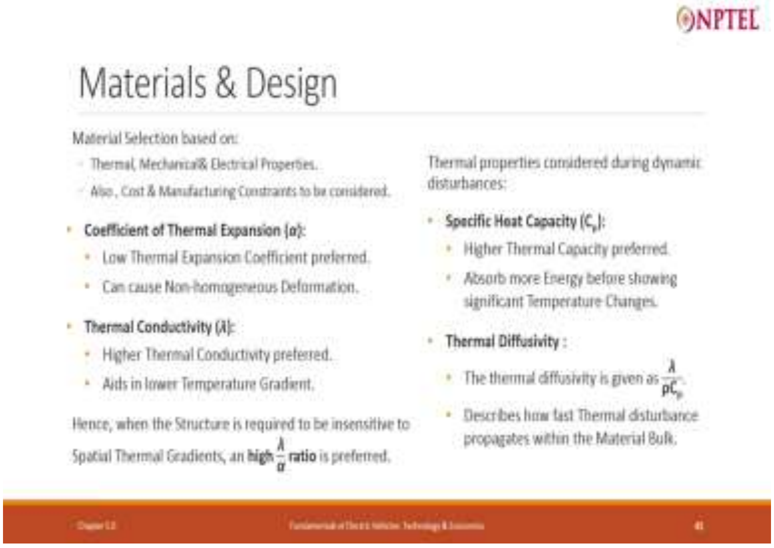

Coefficient of thermal expansion, we want it to be minimise otherwise, what will happen, we may develop thermal stresses. Thermal conductivity, mostly we want higher thermal conductivity so that heat can be transferred quickly. In exceptional cases, we do not want outside heat or environmental heat to be penetrated inside. In that case, we use materials which thermal conductivity is very low.

A specific heat capacity, we want higher specific heat capacity so that without changing the temperature, it can absorb most of the heat. Thermal diffusivity is nothing but is a ratio of thermal conductivity, density and the Cp, heat capacity. And it describes how fast thermal disturbance can propagate in material. What we want? Sometime we want more so that the heat transfer can be fast. Sometime we want less so that my temperature remains maintain depending upon the situation.

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For the external casing of the battery pack, materials for battery pack components for external casing, generally we use metals, aluminium, steels. In the plastic, ABS or poly carbonate, composite, CFRP or Kevlar. Cell/ Module holders, generally we use aluminium with insulation, we can also use plastics; polycarbonates and ABS. Busbar; copper, aluminium, and nickel preferably use everywhere. Cold plate for thermal management, aluminium base with the copper tubing.

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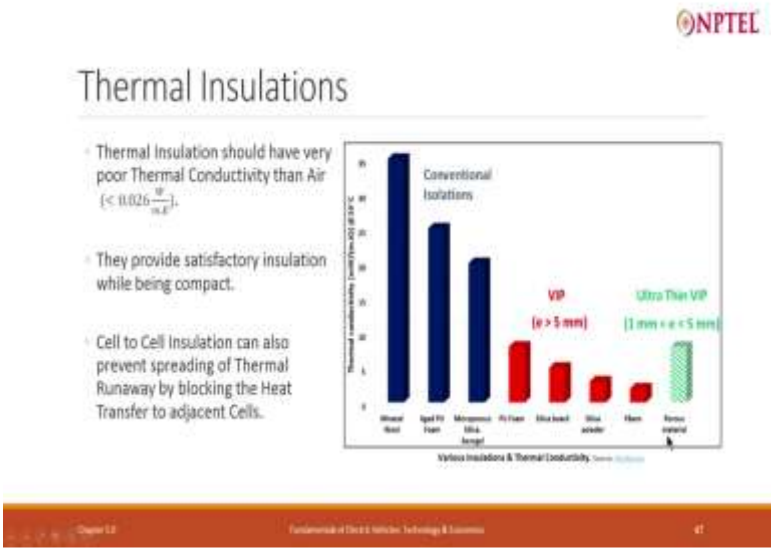

Now thermal insulation; where we require thermal insulation is order casing so that that my environmental conditions should not impact my battery much. If I have a passive thermal management system, I do not want to get it disturbed by environmental condition. Also, we want cell to cell insulation so that in the event of thermal runaway, the heat should not penetrate to other cell to ignite it for thermal runaway. In such cases we want to prevent the heat within that cell itself.

Right side we have a chart. We have different materials there and based upon our requirement we select one of them. Mineral wells, mineral wools, aged PU forms, microporous silica, aerogel these were used conventionally. Recently we are using PU form, silica board, silica powders, fibres. Further, we are using porous materials where air acts as a very good insulator.

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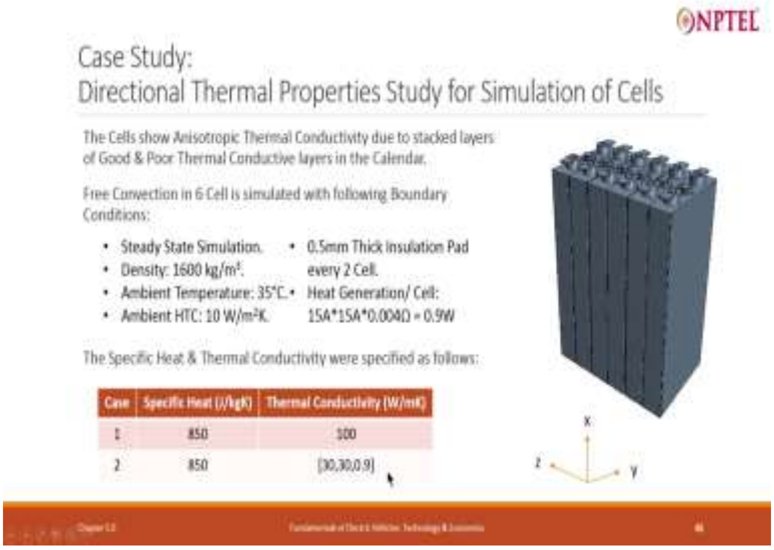

Now, I am showing you the case studies of a directional thermal conductivity. In the cell, we have 3 direction, X, Y and Z. Not in all the direction, because of the material filling inside, the thermal conductivity is same. It is different in different directions. So, what we have done, we have taken 6 cells arranged together and have done a simulation. We have done a steady state, steady state generally can be achieved in 30 minutes and above. So, if you are running at 1C, after half an hour, it is almost reaches to a steady state.

0.5C, it can run for 2 hours in 30 minutes, 35 minutes, it reaches to a steady state. Free convection means natural convection has been considered. All the parameters has been given here, density, what is the ambient temperature, ambient heat transfer coefficient, what the insulation pad we have used between the cells and the heat generation which we have calculated here. The thermal impedance has been taken here 4 milliohm which is realistic value.

The specific heat and thermal conductivities are given. In the first case, consider the uniform thermal conductivity in all or isotropic thermal conductivity in all direction. And in the second case, the thermal conductivity change in all 3 direction. In the first case, it was 100 watt per metre per kelvin. In the second case, X Y Z 30 watt, 30 watt, and 0.9 watt per metre per kelvin.

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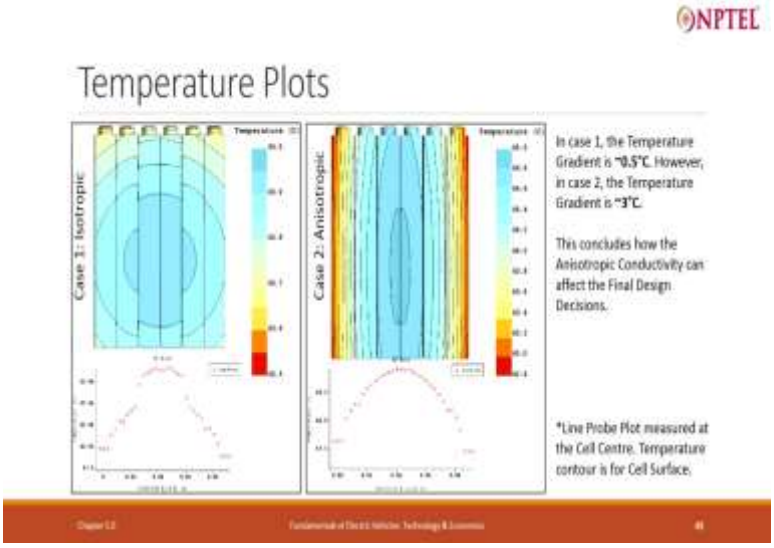

When the thermal conductivity is isotropic that same in all the direction. What we see, my temperature has reached to the 45, 44 degree, if you go back here, my ambient condition is 35, steady state that means basically is battery is fully (discha) has discharged fully. So around 44 degree C it has reached. This is the temperature on this direction you see here this is how it will change.

Now, with anisotropic that means, thermal conductivity is different in different direction. If you see here, it is going to 45 degree, but you see the temperature distribution difference. Now, this is more uniformly, temperature is more uniform here. However, here the temperature is not uniform the temperature gradient here is hardly 0.1 degree in this case. Or I can consider around 1 degree. However, in this case you see I have red lines also here and the blue lines here also, around 3 degree, temperature gradient.

However, we always want to minimize the thermal gradient. So, in the case of isotropic, we have a temperature gradient of 0.5 degree C. In the case of anisotropic thermal conductivity we have a temperature gradient of 3 degree. So, while fusing the thermal management system, we also have to look upon the thermal conductivity in the direction, in which direction it is better so that we can take most of the heat from that direction.

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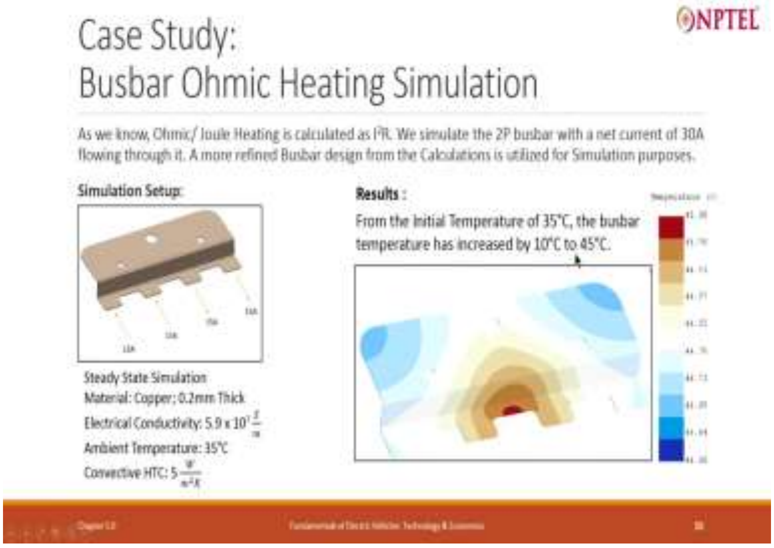

Now, in Busbar, again current is flowing. How the heat will take, how much heat will come in that? What would be the temperature? Again steady state stimulation where we have done, we have given you all the properties here, electrical conductivity this much, temperature of ambient this much, convective transfer coefficient 5. You see the results. At this it is 44, here somewhere it is 44.6. However, the ambient condition or initial condition was 35 degree, so there is a 10 degree temperature dip, increase.

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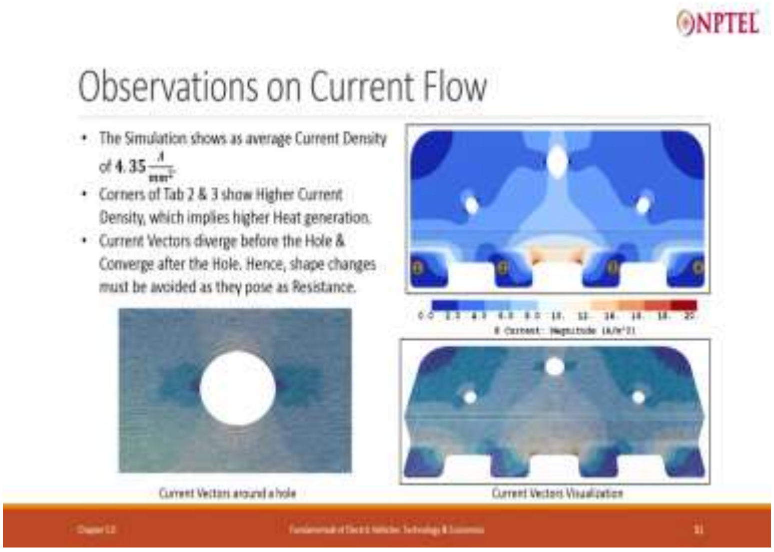

This map shows current flow, how the current is flowing. It is not uniform exactly. The current density the 4.35 ampere per mm square. So, you need to look upon how the current is flowing, it should be uniform basically. So, wherever there is a hole, because of that the current density changes drastically at the corners. The current vector around the hole, now take this hole and you see how the current is flowing, so just passing through.

So, uniformity of current is also important factor because I square R, if some place current is very high, let suppose if my this tip, if current is very high, what will happen? My this tip temperature would raise much more than other tip and then that tip may melt and other tip will still working, but one leg has gone now.

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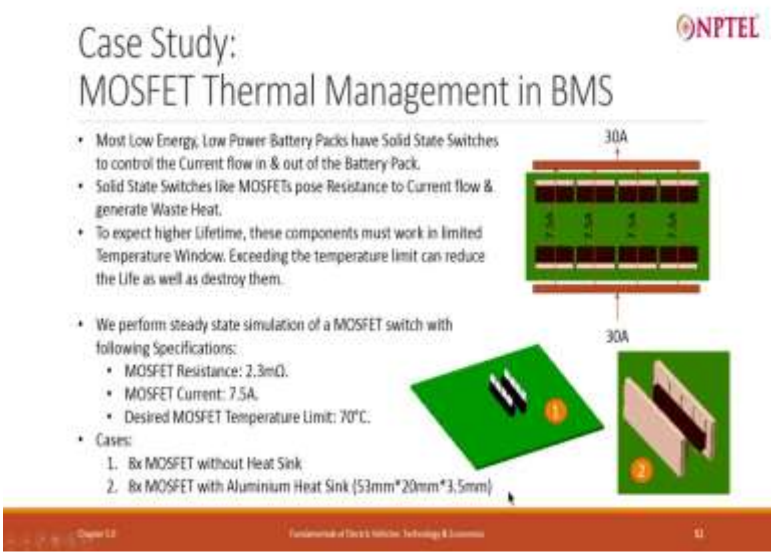

In BSM MOSFET, now we have multiple switches, MOSFET is acting as a switch. Now, current is equally distributed in all the MOSFETs. If some MOSFET, if the my current path what I have shown you in busbar is not equal, what will happen? Some MOSFET will get more current, some MOSFET will get less current. In that case, there would be a uneven temperature, one MOSFET will fail, other MOSFET will remain same there.

Now, here we have considered the same current in all MOSFET. MOSFET resistance we have given, MOSFET current given. What is the temperature limit of MOSFET that also we have given. So, total 4 MOSFET plus 4 MOSFET, 8 MOSFETs. Aluminium heat sink we have provided.

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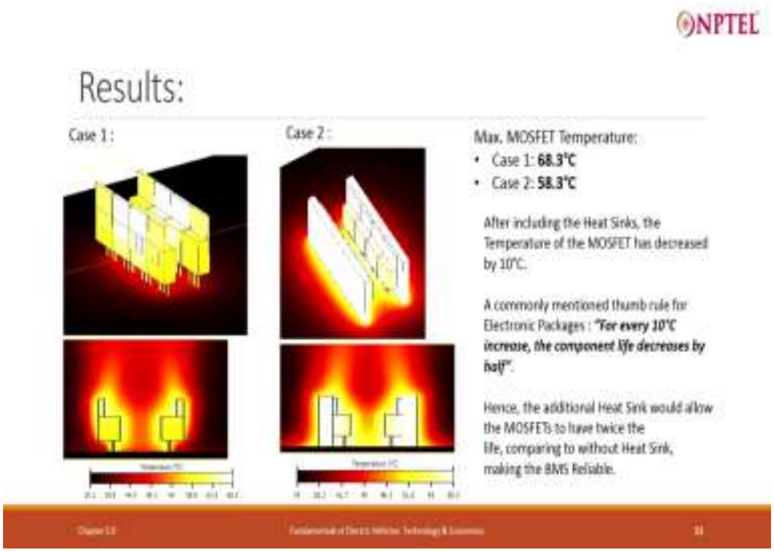

So, maximum MOSFET temperature in the case 1 has reached to 68.3 degree centigrade. What is the cases? 8X MOSFET without heat sink and case 2 is with heat sink with 1C discharge. 1C discharge is 30 ampere which we have divided into 4 MOSFET; 7.5, 7.5, 7.5 and 7.5. My temperature has reached to 68.3 degree centigrade. In case 2, it is 58.3. So, a simple heat sink has helped us to reduce the temperature by 10 degree C.

And you know in electronics part every 10 degree C increase in temperature reduces the life by half. So, if you would have gone 1000 hours at 58.3 degree C, with 68.3, it will go only for 500 hours. Now, this heat sink is a plain heat sink, can we make it corrugated or mikcrofyn? My temperature maybe further down, so I could increase the life.

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Now next Module Thermal Management; the same pack what we have taken 2P16S. We have done all the 3 simulations, natural convection, forced convection and cool plate cooling, active thermal. Second and third is part of active thermal management, first one is passive thermal management. We have done steady state stimulation, ambient condition 35, heat transfer coefficient for natural convection, 2 watt per metre square per kelvin. For natural convection, it is, for natural convection for 30 watt per metre square per kelvin for forced convection.

And in the case of cold plate, we have we are maintaining the cold plate temperature at 17 degree centigrade. Heat generation in each cell remain same in all the 3 cases, 0.9 watt.

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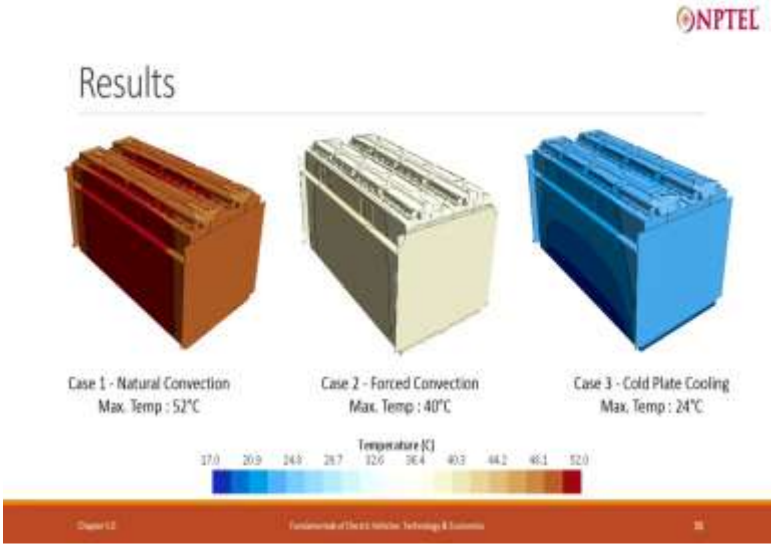

In the natural convection and my ambient condition is 35, my temperature reaches to 52 degree centigrade. In the forced convection, what is happening now? 40 degree C. So, there is a reduction from 52 to 40 degree C. 12 degree centigrade we are able to reduce by just changing the methodology from natural convection to the forced convection. And cold plate where we are maintaining the temperature of the cold plate by circulating the cold water or by direct expansion, refrigeration system, my temperature is 24 degree.

I can maintain this temperature always by changing the flow rates for different C rates. So, what would be the best thing to do? Active cooling system, but it is such a small pack, 1.6 kilowatt, 1.7 kilowatt. A active thermal management system especially with the cold plate cooling itself will take half of the energy in this case. So, generally for a smaller pack, we always try to go for a natural convection or forced convection, but at ambient temperature.

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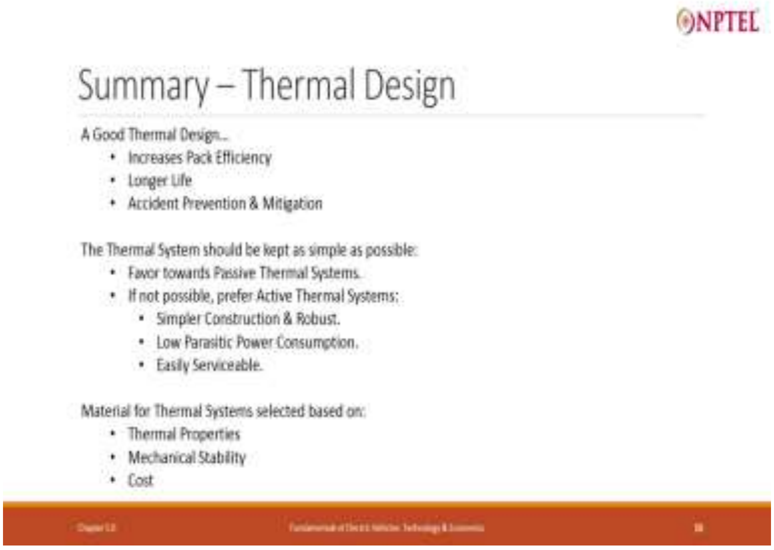

I will summarise this chapter now, sub-section of this chapter. A good thermal design increases pack efficiency, longer life, its also helps in prevent accidents. Accidents could be busbar melting, wire melting, bulging of the cell and extreme thermal runaway. We if it cannot stop completely, at least it will mitigate the effect. Always we favor to passive thermal management system because it would not take energy from the battery pack. If needed, we go for active thermal management system, but for bigger packs.

It should be simple in construction, low parasitic power consumption, easily serviceable. Materials; we have to carefully select a material based upon our requirement, insulative or conductive. We also have to look upon mechanical stability of the parts for thermal management system and obviously, the cost.

So, what we have done in this chapter? We try to understand the heat load or heat generation in the battery. We also try to understand what are the environmental factor affecting that one. And based upon heat load heat generation of the battery pack, we learned about what type of thermal management system we should utilise; active or passive. The active thermal systems, thermal management system are generally used where we have a bigger pack generally for more than 10 kilowatt hour batter pack.

Passive, we can use for a smaller pack. There are merits and demerits in both. We have also understood a simple graph base upon a heat generation and the heat transfer coefficient, what would be the temperature gradient? What would be the best thermal management system for that particular fact? It should be natural or forced, in forced; air cold or water cold or direct expansion.

If it is passive, what should we do? It is a heat sink we use or PCM we should use? We have also learned about what type of material we should select for thermal management system. Various part of the thermal management system and then we have seen one of the property, thermal conductivity which is generally anisotropic. So, if we assume it isotropic and if it is an anisotropic, what will happen?

If we use it judicially we can know which surface we should utilise for heat transfer or where we can extract most of the heat from the battery. What would be the impact on the temperature gradient? Then, we have also seen in the busbar how the temperature is increasing, why thermal management of busbar is also required? We have seen MOSFET, a switching device, electronic device.

How a simple passive thermal management system utilising the heat sink can reduce the temperature drastically? Can improve the lifecycle and then finally, we have done simulations over a battery pack, natural, forced, and the cold plate system. It seem to be seems that cold plate cooling system is the best, but however, it is a very difficult to provide such systems in a very small battery pack of 2 kilowatt.

So, generally we use those pack, those type of active thermal management system on higher capacity packs. For lower capacity packs, we try to go mostly with natural or passive thermal management system or at max, the ambient air force convection. So, with this I am ending this chapter sub section. Next class we will go for the electrical design of the battery pack.