Electrochemical Energy Storage
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Module - 07
Introduction to battery pack design
Lecture - 34
Introduction to Thermal Management: Active Thermal Management System, Passive Thermal Management System, Temperature Protection and Insulation

Welcome to my course Electrochemical Energy Storage. This is module number 7, Introduction to pack battery pack design. And this is lecture number 34 where I will be talking about the Thermal Management System.

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Now, in this particular topic the lecture, we talked about thermal management system. And first we will introduce why they are required. And why the requirement of cooling is required and sometimes heating is also required. And like you remember the balancing, we have active thermal management system and passive thermal management system; what they are we will be talking about.

And temperature, protection, insulation, measurement this type of concept will also be developed. So, how you can measure the temperature, how you can protect the self from thermal run out, what is the use of insulation; so this are also important. This is the typical battery keys that is fabricated in my laboratory.

So, you this the out outside case of the battery and the whole module is they are kept inside which is not shown here. There are lot of holes you can see for the connections or different components to take their connections out. And here, there is a small space for the LCD board where you can see the voltage temperature inside the pack.

And typically, you can have different types of design of this battery pack. So, whatever we developed, I thought it is a good idea to show you that this is one of the versions of our battery pack developed in our laboratory. So, we will talk about the thermal management inside the battery.

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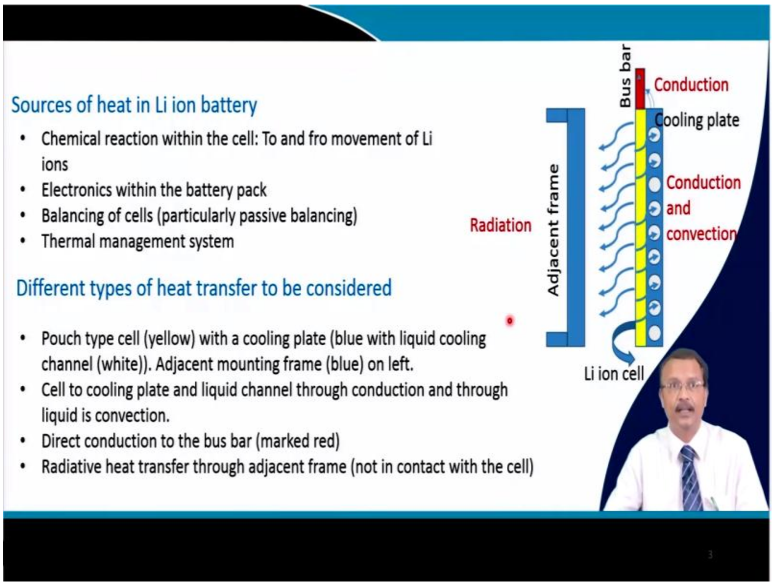

So, what are the sources of heat in lithium battery? Almost it is unavoidable. And this is due to the chemical reaction within the cell. And lithium is going to fro from cathode to anode during charging and during discharge from the negative electrode to positive electrode. So, it generates heat. You are using lot of electronics. You know that in the last lecture, we talk about the master control board, then the slave boards and lot of electronics are involved and they also dissipate heats.

Third one is if you do particularly passive balancing, then you are basically discharging it through a register so, that also generate lot of heat. And you need a thermal management system, otherwise the battery will be over heated and there will be condition where there is a thermal run away. So, you need to take care of it. So, you do need a thermal management system for larger battery pack.

Now, all different types of heat transfer that may be considered. So, here is one schematic you can see the yellow part. This one is a pouch cell and this is directly connected to a cooling plate. So, the blue one is a cooling plate and it has holes, the channels which is marked white. And, so this cooling plate this connects the battery is connected with this and you have the bus bar. So, to connect this pouch cell with another pouch cell.

And then you have a frame to get hold of all the battery in place, in inside the model module. So, if your things your battery pack is something like this, then you can see that cell to cooling plate and liquid channels through conduction and through liquid is convection.

So, this part here; when the cooling plate is adjacent to the cell, then heat through conduction is taking place and through this hole, liquids are flowing. It is a possibility not that that every battery pack you have all this kind of mechanism, but this is possible that in the cooling plate you need to pass fluid. So, the heat will be taken out from this battery through this flowing liquid. So, that is a convection part.

And here in this case, there is a direct conduction. So, this will also get heated. So, it will take the bus bar will take the heat from the pouch cell. So, this is conduction. And also, there will be radiative heat transfer. So, this is a metal frame. So, when the battery is hot, then there is radiative heat transfer from this place to the adjacent frame.

So, in other words that you can consider the conduction part through here and through the cooling part, then convection through the liquid which is flowing and also to the radiation part where heat is basically radiated to the adjacent frame.

So, all kind of heat flowing mechanism you can consider, when you are talking about the thermal management system of a big battery pack. For smaller pack, we do not care there are ways to do that. So, in fact, in our small pack whatever we are developing. We know, we are aware of the requirement of the thermal management, but still we have not done anything very specific, but for bigger pack certainly you need to do something.

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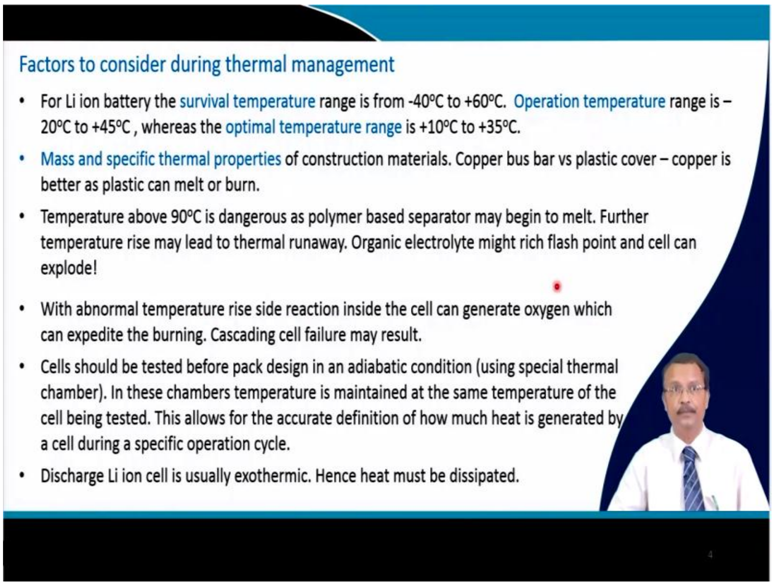

So, again the factor that you should consider while you design the thermal management is. First one, the lithium battery their survival temperature is usually in the range of minus 40 to plus 60 degree Celsius. And mostly it is considered the electrolyte is playing a major role. Once was the temperature is very low, then there is a possibility that the electrolyte may freeze. And if it is high temperature, then there is a possibility to reach to the flash point.

So, accordingly we select the solvent of the electrolyte and I had a detailed discussion when I talked about the electrolyte in one of my earlier lectures. But usually the operational temperature range is not this, but this. And this is particularly in Indian perspective this is a good consideration 20 degree Celsius to plus 45 degree Celsius particularly in the summer time.

And optimal temperature range actually one should keep from 10 degree Celsius to plus 35 degree Celsius. But remember that all this things they depend on the geographic locations. There are certain locations where the temperature will always be pretty high. There are certain locations in the globe, then most of the part they will have very low temperature. So, accordingly your thermal management will change. So, that is one part that is one should consider.

The mass and specific thermal properties of the construction material that is important. The usually, copper bus bars are used and some cases as I have shown that a plastic cover that is also used to connect the cell. So, plastic cover then a metal strip and then you screw tight it. So, copper is of course, better than plastic, because when the temperature is raised, then the plastic can melt. So, bigger battery you should consider that.

Temperature over 90 degree Celsius is dangerous as polymer based separator may begin to melt. And that also, I talked about it right. So, if it melts, then it the pores are clogged and lithium cannot pass through it. But if the temperature is further raised, then it will lead to thermal runaway.

Organic electrolytes they might reach to their flash point and cell can even explode. So, one should be very careful that this kind of situation particularly for a bigger battery pack that should not occur. So, a driving a motor car you do not want that your battery explode, because you are carrying the battery with you. So, that is extremely dangerous.

So, with abnormal temperature rise, side reactions in inside the cell that can generate oxygen which can expedite the burning, that is quite obvious. And same thing happens for over charging the batteries. Oxygen can generate and this oxygen they will expedite any kind of burning operation which might occur to the whole battery pack. And this is basically a cascading effect and failure certainly will occur.

So, cells they should be tested before pack design in a adiabatic condition. So, a specific thermal chamber that is required for this purpose and recently we have acquired this in our laboratory. I will show you the picture. And this is yet to be installed, but we have gotten this.

In these chambers temperature is maintained at the same temperature of the cell that is being tested. So, it is basically a adiabatic kind of test chamber. So, this actually will help you to accurately define that how much heat is generated in a specific operation cycle.

Remember, this operation you can do at various type of C-rates. So, you can for example, charge the battery at 10 C-rate. So, within 6 minutes, the battery will be fully charged. So, suddenly it will generate more heat. And you can do it different types of cycle discharging very fast or discharge at a very low rate and see that what is the kind of temperature is raised of this individual cells.

And usually, the discharge of the cell is exothermic and heat must be dissipated. So, before you do this design this thermal management system, you should check the individual cells whatever you have procured or you are making in your laboratory individually using this specific thermal test chamber. That is very important.

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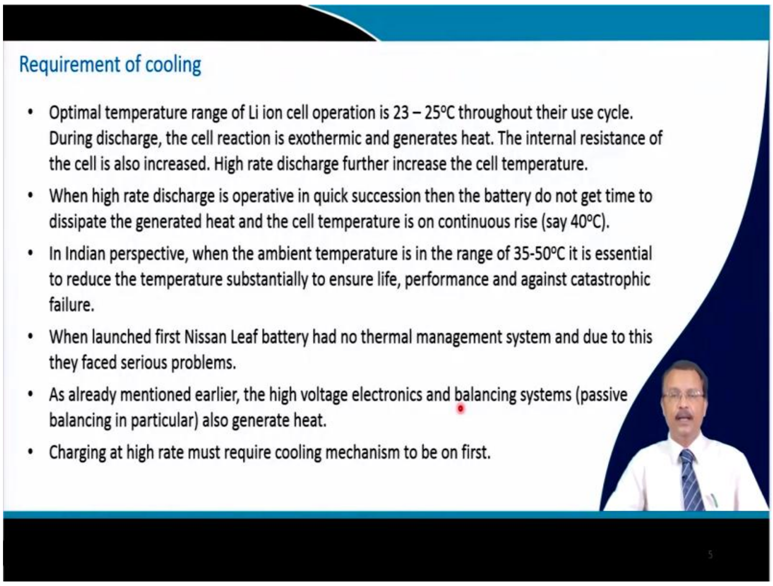

Not always heating is required, sometimes cooling is also required. So, if I consider that optimal range is in between 23 to 25 degree Celsius the normal room temperature throughout the their cycle, then it is ok. During discharge the cell reaction is exothermic and it will generate heat. The internal resistance of the cell also will increase the high rate of discharge further increase the cell temperature. So, this will be deviated from this right.

So, this all this during operation actually the battery will certainly be hot. When you are using your laptop you have experienced it that you do lot of different applications, then you will fill the heat. And small fan is embedded in the laptop to drive away the excess heat through a window.

So, when high rate discharge is operative in quick succession then the battery do not get time to dissipate and quite obvious right. So, you are discharging it continuously at higher discharge rate. So, the cell temperature will certainly be raised, because if you discharge it very fast and then you have a risk period or discharge at relatively lower discharge rate then by that time it can dissipate, but this is not the case.

Particularly in Indian perspective, when the ambient temperature is in the range of 35 to 50 degree Celsius. It is essential to reduce the temperature substantially to ensure the life or performance against a catastrophic failure.

So, when launched for the first time you know that Nissan Leaf battery, they had no thermal management system. And due to this, due to the thermal lack of thermal management system in the battery, they face serious problem. And the high voltage electronics and balancing circuit particularly the passive balancing, they also generate heat.

So, charging at high rate they also, require some kind of cooling mechanism. So, for a bigger battery as I said you have number of sources of generation of heat and this must be managed.

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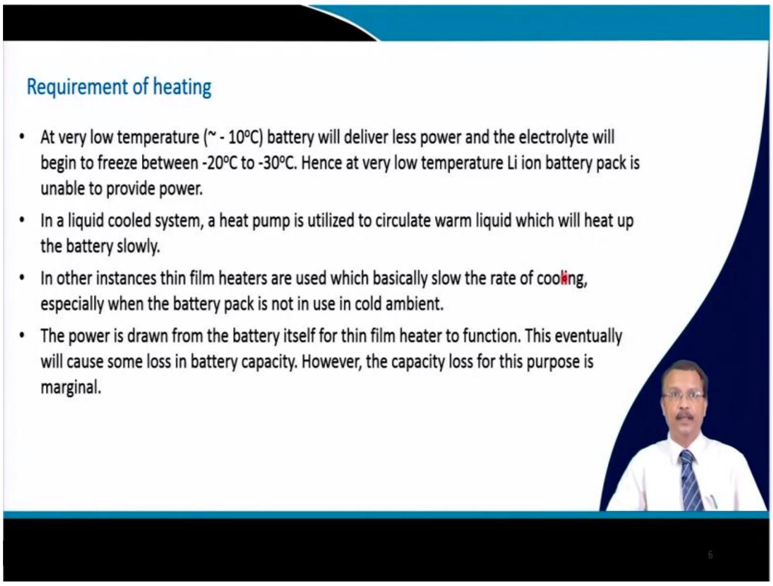

Now, not always as I said that cooling is required. Sometimes, you need to heat the battery also. For example, at very low temperature say minus 10 degree Celsius, the battery will deliver less power and the electrolyte will begin to freeze at typical temperature. You remember in the electrolyte we have a lithium-based salt and a cyclic and a linear types of mixture solvent.

So, in this temperature minus 20 to minus 30 degree Celsius they try to freeze. So, at very low temperature, lithium-ion battery pack is unable to provide you power. So, you cannot generate power out of this battery. So, in a liquid cooled system; that I showed the first schematic the cooling plate that you pass a fluid it can take the heat from the battery. So, in the same system a heat pump is utilized to circulate instead a warm liquid which will heat up the battery very slowly and in cold country it is done.

In other instances, thick film heaters; sorry, thin film heaters are used which are basically slow the rate of cooling. It is not really heating, but since the ambient temperature is too low with the heater this rate of cooling you are controlling. So, that is also done. So, not always cooling is required sometimes, heating is also required.

The power is drawn from the battery itself for the thin film heater to function. So, you are loosing your part power this. So, battery power whatever you are doing you are getting the energy from the battery itself. So, that will eventually cause some loss of battery capacity. So, when you design the battery capacity for your own use depending on your cooling requirements so you will have to take into account this loss.

So, the capacity loss for this purpose of course, that is marginal that is not that much to slowly heat the battery in a cold ambient.

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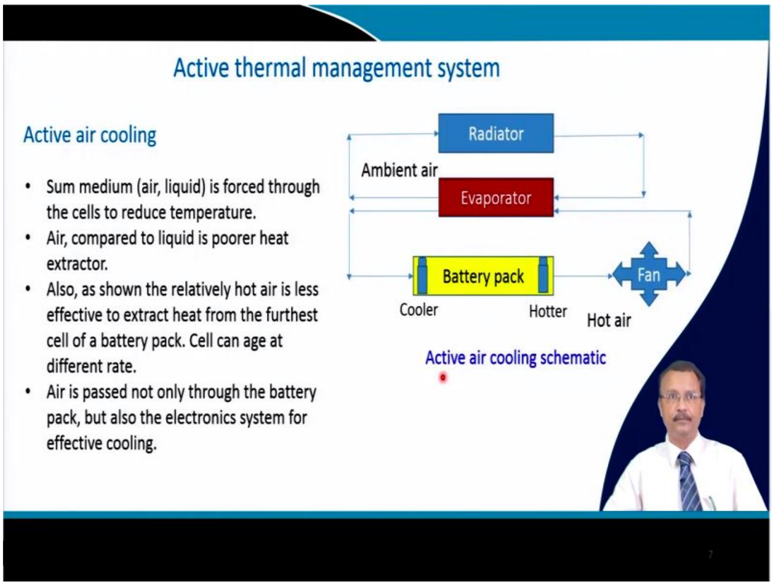

So, active thermal management system is a active air cooling. So, sum medium air or liquid that is forced through the cell to reduce the temperature. And this is a schematic of active air cooling system. So, here you can see that you have a radiator here. So, ambient air is passes and then there is a evaporator and then this basically this cold air that is passed through this battery pack. And then, it is suck by this fan and again they put to the evaporator.

So, this kind of system you can do and all the energy you will have to take from the battery itself. So, air compared to liquid is a poorer heat extractor. So, air cooling is less effective as compared to if you cool it through passing a liquid. So, as shown here, a relatively hot air is less effective to extract heat from the furthest cell of the battery pack.

So, this particular region this battery will be cooler as compared to this one, because by that time it reaches the air cold air reaches here. So, it takes the heat from this batteries, so it will be a bit hotter. So, air is passed not only through the battery pack, but also other electronic system they also generate heat. And this is the example of active thermal management system.

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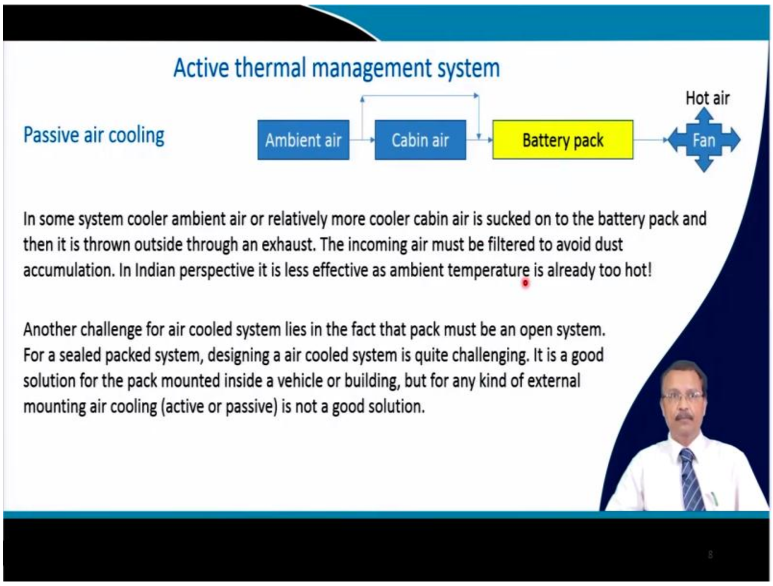

Passive air cooling that is also quite interesting. You have the ambient air here, it is not very effective in our perspective. So, unless you are using a air conditioned car. So, this air is sucked and that partially cool the battery pack and the hot air is discharged in the ambient. So, in some particular system cooler ambient air or relatively more cooler cabin air that is sucked to the battery pack as I mentioned and then thrown outside through a some kind of exhaust.

So, this incoming air must be filtered. So, the dust should not be accumulated in the battery pack. But as I said in Indian perspective it is less effective, because this ambient air particularly in the summer time is too hot and that will not be useful to cool the battery pack.

Another challenge for air cooled system lies in the fact that the pack must be open systems. So, the battery must be open system if it is a sealed pack, then designing of air cooled system is quite challenging. So, it is a good solution for the pack mounted inside the vehicle or building, but when it is any kind of external mounting air cooling whether it is active or passive that is not a really good solution. So, depending on the space of this battery placement, this kind of management will be important.

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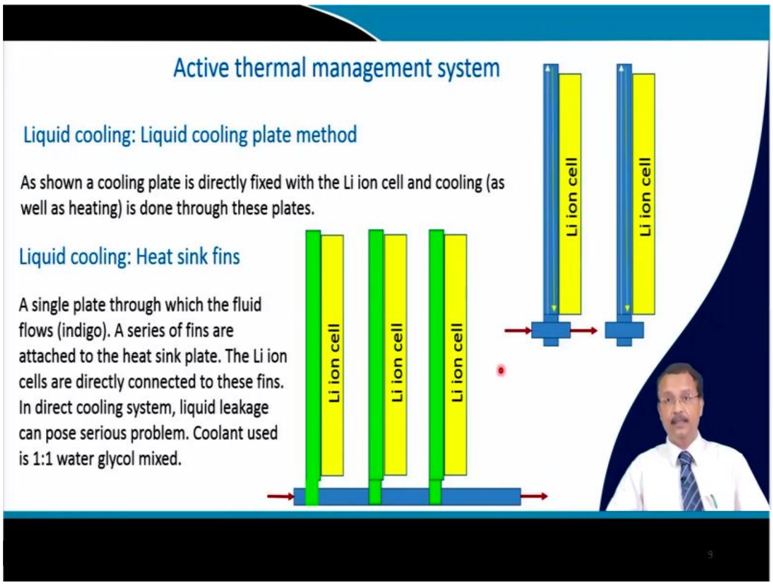

So, this is another example of your passive air-cooling system. And earlier we talked about active air-cooling system, where you are actually making the air cooler and then that is used that thing to cool your battery and this one is passive one.

So, liquid cooling that is another way. So, one is liquid cooling plate method. So, this schematic already I showed earlier. So, your lithium-ion cell is here. And then, through this you are passing a liquid and this liquid is circulating. So, that takes away the heat and then this heat is taken away. So, this is a liquid cooling plate method.

And another one is a heat sink method. So here, a single plate is used where from the liquid is thrown liquid is passed and this battery is connected with a series of fins. So, that is attached to this heat sink plate. So, this lithium cell they are directly connected to this fins. So, all this cells are connected to this fins.

So, in direct cooling system, the problem is the liquid leakage. So, if the liquid leaks, then the battery pack will be messy. So, that poses a serious problem. So, usually the coolant that is used is the normal coolant which we which usually we use for the car which is 1 is to 1 mixture of water and glycol. So, that is by wet fraction.

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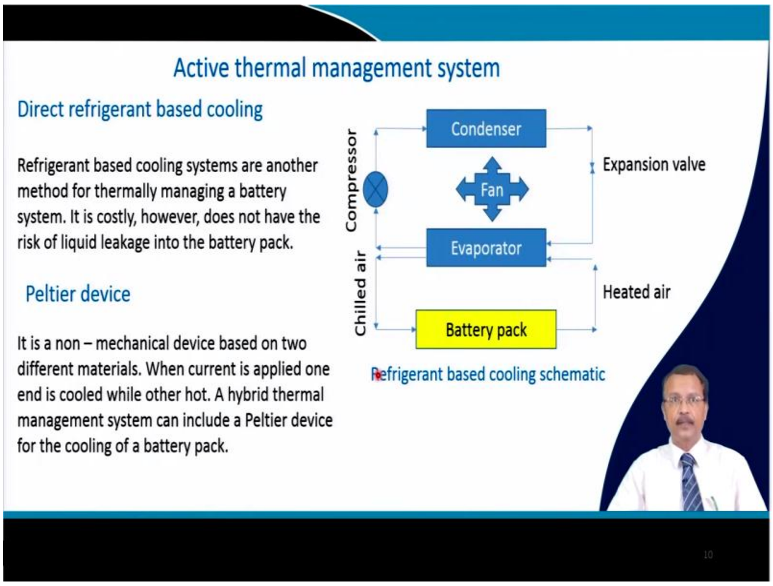

There are other ways which is a bit expensive that is direct refrigerant based cooling. So, refrigerant based cooling is another method that is to manage the battery pack system as I said it is costly. So, there one use a compressor and the condenser with a expansion valve. It goes through the evaporator and then the chilled air is fed to the battery pack and the hot air is discharged in the ambient. So, this is a bit expensive to cool the battery you are using a refrigerant; a refrigerating system. So, but depending on the volume of the battery pack, this is also another solution.

Another typical solution is the Peltier device. It is a non-mechanical device. And you know what is a Peltier effect; when the current is applied in the coolant of two different material the junction. So, one end is cooled and another one is hot. So, a hybrid thermal management system can include a Peltier device for the cooling of a battery pack along with some other thermal management system.

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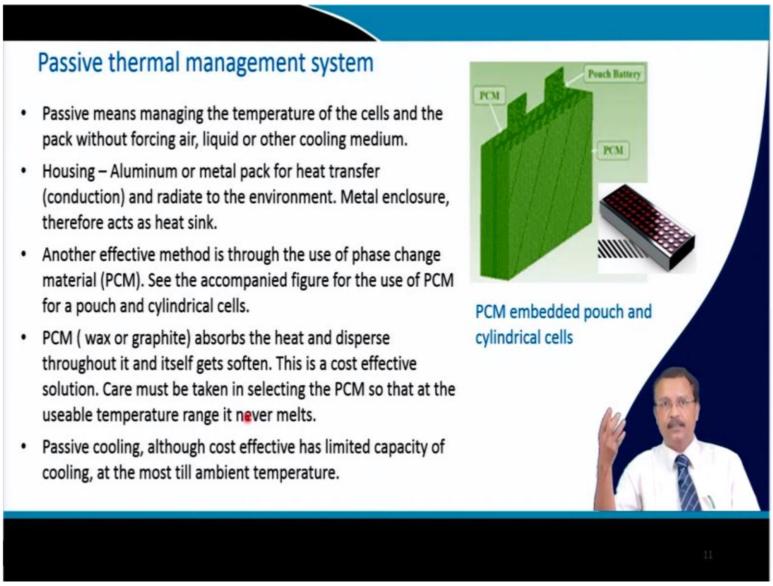

Now, this all are part of active thermal management system. You can have a passive thermal management system where automatically it gets cooled not really automatically. So, passive means the managing the temperature of the cells and the pack without forcing any air or liquid or other cooling medium.

So, in one way it is good. It is not taking any energy from your battery pack. So, you are using the housing. So, one such housing I showed towards the beginning. So, it is basically a aluminum based alloy, a metal pack or any other metal pack for heat transfer through conduction and also it radiates to the environment. So, metal enclosure therefore, act as a heat sink for this kind of battery. So, that is one way.

Automatically, you will have to place your battery module to make the pack inside a metal enclosure and that also acts as a EMI shield. So, that is two way purpose it serves. Another effective method is through the use of a phase change material, which is abbreviated as PCM. And as you can see the figure that both for pouch cell. So, the pouch cell is here and then, it is just sandwiched between two PCM.

And here for cylindrical cell, you have the whole block of PCM and you make a hole and then you put all your cylindrical cells inside this phase change material. So, both were pouch cell and cylindrical cell. The phase change material which is basically wax or graphite that is used and basically it absorbs the heat and disperse through it throughout it and it itself gets soften. It utilizes the heat and it gets soften.

This is one of the most cost-effective solutions that one can think of, but you should take care for selecting the PCM. So, that at usable temperature range it never melts it just gets soften. If it melts then, again it will create problem within the whole; within the battery pack.

So, passive cooling that is certainly cost effective, but it has certainly limited capacity of cooling and as you can understand till ambient temperature it can cool. So, if your ambient temperature itself is quite hot then passive cooling may not work and it will not work.

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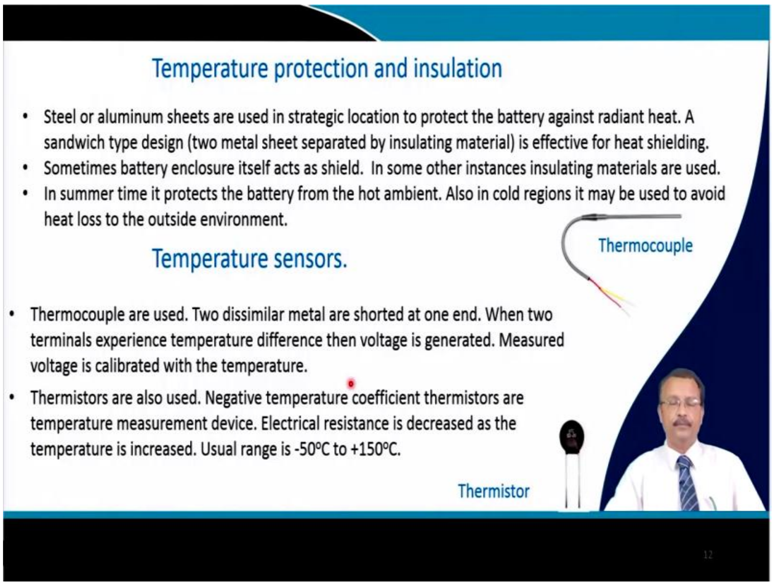

Temperature protection and insulation is also required. So, steel and aluminum sheets that are used as a strategic location to protect the battery against the radiant heat. A sandwich type design two metal sheets separated by insulating material is quite effective for the heat shielding. Same like your furnace construction you have metal sheet and you have refractory therein.

Sometimes battery enclosure itself act has a shield. In some other instances insulating materials are used. In summer time, it protects the battery from the hot ambient. In cold region also that may be used to avoid the heat loss from outside environment. Temperature sensors usually thermo couples are used. You know the thermo couple are two dissimilar material which are shorted at one end. When two terminals experience the temperature difference then a voltage is generated and measured voltage is calibrated with the temperature.

So, thermo couples are used. Or in some cases the thermistors they are used. So, negative temperature coefficient thermistors, these are a temperature measurement device. And in this case for negative thermistors, the electrically resistance is decreased as the temperature is increased. So, this white band gap semi conducting ceramics are used for this. And usually, the temperature range is minus 50 to 150 degree Celsius which is particularly useful for the battery pack. So, the typical thermo couple and thermistor is shown.

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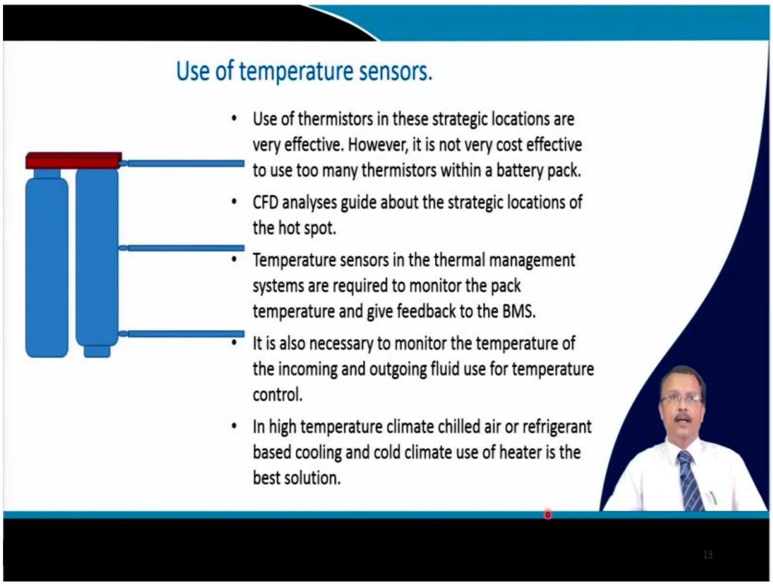

Now, where should we put this kind of temperature sensor? So, use of thermistor in these strategic locations are very effective. So, either you can put it in the bus bar of course, you cannot put it inside the cell. So, you will have to put it at the surface of the cell. So, in the bus bar is one location where the temperature should be monitored, second location is here as you can see, and third one is just at the middle of the series connected pack.

So, it is not very cost effective to use too many thermistors within the battery pack. So, strategic location we will have to put these thermistors. Computational fluid dynamic analysis guide about the strategic location the kind of heat generate a heat map is theoretically simulated. And in strategic locations, this thermistors or thermocouples are placed.

Temperature sensors in the thermal management system required; that is to monitor the pack temperature and give back to the BMS that ok in this location the temperature is going high. So, you do something for the cells therein. So, some are faulty. So, accordingly BMS takes care of it.

And it is also necessary to monitor the temperature of the incoming and outgoing fluid that you know in case of this active cooling system. So, you are using the coolant. So, the temperature monitoring of the coolant is also equal. And in high temperature, climate chilled air or refrigerant based cooling and in cold climate use of heater is the best solution for the optimum performance of the battery pack.

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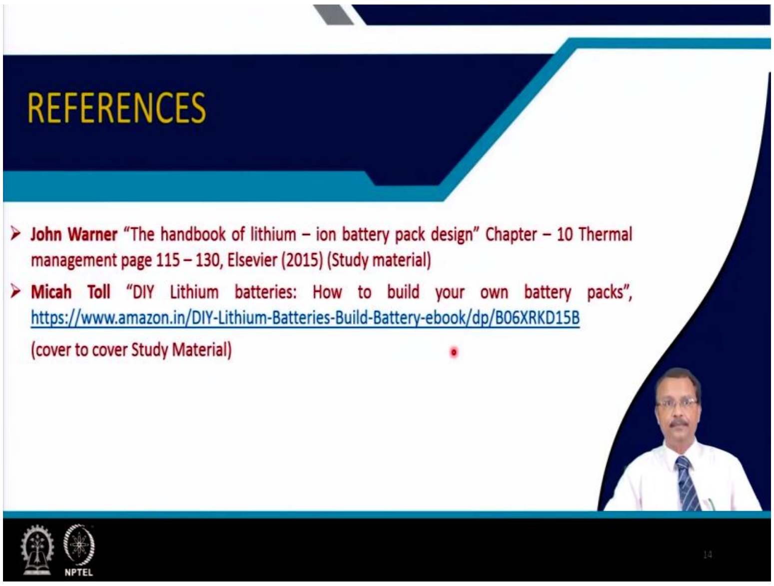

So, the study material is again the book by John Warner "The handbook of lithium-ion battery pack design" Chapter 10 Thermal management system. And also the book by Micah Toll. And as I told, that you should read cover to cover. So, the whole thing is important for you to understand that how to make a battery pack and it is written in a very very lucid language. So, you will enjoy in reading both these two books.

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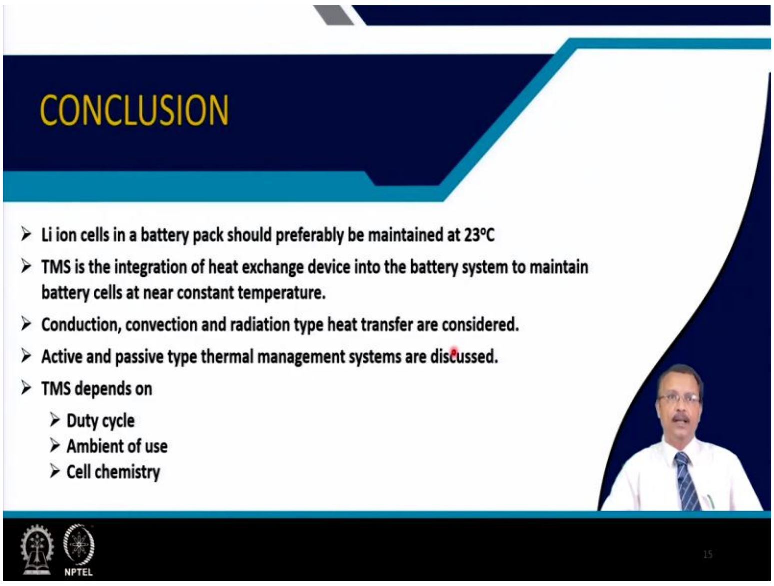

So, in this particular lecture we talked about lithium-ion cells in a battery pack should preferably be maintained at a temperature around room temperature 23 degree Celsius. Thermal management system is the integration of heat exchange device into the battery system to maintain battery cells at near constant temperature.

Conduction, convection and radiation type heat transfers are considered. Active and passive type of thermal management system we have discussed it. And the thermal management system of course depends on the duty cycle, then the ambient where the battery is kept and of course with cell chemistry.

Thank you for your attention.