THERMAL MANAGEMENT IN EV

Sayed Umar Masood[1], Mohd Qasim Farooqui [2], Zishan Shahzad[3], Moazzam Farooque[4]

[1]Sayed Umar Masood, Dept. of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India
[2]Mohd Qasim Farooqui, Dept. of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India
[3]Zishan Shahzad, Dept. of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India
[4]Moazzam Farooque, Dept. of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India

---***---

Abstract - *Optimum performance and efficiency of battery packs can be obtained in certain Temperature Range; to achieve this we must have a fail-proof thermal management system.*

Extensive Simulations were conducted on the battery model with different cooling systems like Air cooling, Liquid Cooling, Thermoelectric Cooling (TEC) and thorough results were taken down. All three cooling systems have been extensively studied and it is found out that they can lower the temperature of battery significantly, but Thermoelectric Cooling shows potential drop in battery temperatures to desired range, ultimately making the battery Thermally safe, Stable and efficient.

Also, Simulation results were analyzed for further improvement in the thermal efficiency of the battery pack.

1. INTRODUCTION

Advances in electric vehicle batteries have allowed them to deliver more power and require less charge, but one of the biggest challenges to battery safety is designing an effective cooling system. Electric vehicles generate heat when the batteries are discharged. The faster the battery discharges, the more heat it generates. The battery works on the principle of voltage difference, high temperature excites the electrons inside, reducing the voltage difference between the two sides of the battery. Batteries are designed to operate only within certain extreme temperature ranges and will cease to function if a cooling system is not in place to keep them within that operating range. The cooling system must be able to maintain the battery pack in the temperature range of approximately 20-40°C and keep the temperature difference within the battery pack to a minimum (5°C or less).

Here are the parameters that affect battery performance with increasing temperature:
Battery life If the internal temperature difference is large, the charging and discharging rate of each cell will be different, which may reduce the performance of the battery pack. Potential thermal stability issues such as: Overheating of the battery or uneven temperature distribution in the battery pack can lead to reduced capacity, thermal runaway, fire explosion, etc. . Faced with life-threatening safety issues, the electric vehicle industry needs innovation to improve battery cooling systems.

2. COOLING SYSTEM IN ELECTRIC VEHICLES

The basic types of cooling system in electric vehicle are listed below:

1. Lithium-Ion Battery Cooling
2. Phase Changing Material Cooling
3. Air Cooling
4. Liquid Cooling
5. Thermo-Electric Cooling

2.1 Lithium-ion battery

Lithium is a very simple metal and falls under the alkaline group of the periodic table. It has three electrons and an electronic configuration of 1s2,2s1. Lithium has a very high tendency for electron loss, and this area makes lithium very unstable. Although lithium metal oxides are a stable form of lithium. Individual lithium-ion cells can reach very high voltage due to the very high efficiency of metal. A lithium-ion battery consists of several modules connected to a series and each module contains individual cells connected in series and compatible. Lithium-ion battery consists of three main components: 1. Lithium Metal oxide, 2. Electrolyte, 3. Graphite. Electrolyte separates lithium metal oxide from graphite. Lithium-ion batteries operate in two stages: Charging and discharging. During the charging stage, it connects the cell to the power source. It connects lithium Metal Oxide to a direct terminal (anode) and connects graphite with a negative terminal (cathode). The electron in the lithium valence shell is attracted to a fine energy source terminal. Electrolyte acts as a guard and does not allow electrons to pass. Electrons pass through the outer supply and reach the graphite layer, and in the meantime, lithium-ion (Li +) passes through the electrolyte and is trapped in the space between the graphite. When all the lithium-ion is trapped inside a solid graphite sheet, the cell is fully charged.

Lithium-ion and Electron built-in charging is a very unstable platform so when a power source is replaced the load the battery starts to leak out. Lithium-ion travels to the metal oxide by electrolyte to create a stable state of lithium metal oxide. Electrons begin to move to the anode with a load and thus we get electrical energy per load. When all the electrons and lithium-ions return to normal, they discharge the battery. Graphite used in a cell acts as a lithium-ion storage and does not contribute to chemical reactions. This process and electricity also generate heat. Lithium-ion batteries produce heat due to complex internal mechanisms such as: 1) exothermic chemical reactions 2) ohmic resistance 3) cell separation due to battery power differences between charging and charging open circuit4. Lithium-ion batteries get a hot escape under certain conditions. Thermal Runaway is a process in which sensitive temperatures inside the batteries begin to deteriorate dramatically and produce excessive heat. If the heat cannot escape as soon as it is produced this evaporative reaction cannot be stopped. Here, if the proper cooling method is not used to eliminate the heat generated by the cell it explodes. Cell rupture causes side effects. So choosing the right cooling module for such a battery module is important. In this paper, we focus on the cooling methods used.

2.2 Phase Change Material Cooling

A phase changer is something that releases or absorbs enough energy in a phase change to provide a useful thermal or cooling effect. PCM has such a system because of its high ambient temperature. The most widely used PCMs are RT35, RT15 (Ruby Therma 15), EG5 (expanded graphite 5), and EG26. The operating temperature of PCM ranges from -40 ° C to 150 ° C. PCM is the main solution for the efficient operation of an electric vehicle by maintaining a continuous distribution of heat even in any temperature conditions. Divisions: Category Changes are divided into three main categories:

Organic (paraffin compounds, non-paraffin compounds), Inorganic (Salt hydrates metallics), and Eutectic compounds. Alternative organic substances and salt hydrates are preferable when operating at temperatures below 100 ° C (eg Li-Ion batteries). Eutectic compounds can be used at temperatures up to 250 ° C. Organisms have an ambient mixing temperature at a spectrum of 128 to 200KJ / Kg while Inorganic compounds with a range of 250-400KJ / Kg. Organics PCM is usually divided into two sub-categories: paraffin and non-paraffin. Paraffin is tested to be safe, chemically stable, reliable, and inexpensive. In addition, they have a low volumetric elasticity through phase conversion and have a low conversion rate. Paraffin is made up of alkanes chains whose chemical composition and formulas are $CH_3 (CH_2) mCH_3$ and C_nH_{2n+2}. Typically, paraffin phase transformers have a melting temperature and the ambient temperature increases logarithmically with an increase in the number of carbon atoms. Non-paraffin can be classified as esters, alcohol, glycols, and fatty acids. Normally organic PCMs are not paraffin separated by high composite temperatures, non-combustion, low thermal conductivity, wild toxicity, and instability at high temperatures. In addition, fatty acids are a very important subgroup of unhealthy PCMs. They have a higher combustion temperature compared to paraffin and have no problem with thermal hysteresis and subcooling during freezing processes. The chemical structure and formula are $CH_3 (CH_2) mCOOH$ and $C_nH_{2n}O_2$. The thermal conductivity of fatty acids is very low, i.e. from 0.14K / mK to 0.17K / mK. The thermal diffusivities of fatty acids range from 7.5m2 / s to 10-2m2 / s. The advantages of non-paraffin PCMs are good chemical stability, non-toxicity, low volume expansion, compliance with storage properties, high ambient temperature and power fullness, no effect of low cooling and phase separation. Disadvantages of non-paraffin PCMs are more expensive compared to paraffin and salty hydrates. The cost of non-paraffin PCM is about 2 to 2.5 times that of paraffin and more than that compared to saline hydrates. Organic non-Inorganic PCMs are divided into two parts: salt hydrates and metalics. Salt hydrates are a mixture of inorganic salt alloys (AB) and water (nH_2O), forming a compound with a chemical formula similar to AB (nH_2O). In this type of PCM, melting / stabilizing water dissipation / salt flow. This causes the problem of salt hydrates i.e. processes of non-mixing or sedimentation during melting. This is because dehydrated salt is heavier than water and often decomposes at the bottom of the container. When hydration needs to be activated, the system is divided into areas of different salt concentrations, so complete hydration installation is not possible. However, solutions to this problem have already been found, for example, mechanical stimulation, installation of PCMs to avoid the separation of depleted salts in their water, and the addition of special thickening materials. Another problem with salt hydrates is their high cooling, due to their low nucleation properties. It means that the nucleation rate of salt hydrates is very low in the transition temperature and the material needs to be cooled very hard before the nucleation can act naturally on salt hydrates. It means releasing heat energy stored in the material at a very low temperature and thus reducing the energy efficiency of the heat storage system. There is little evidence that the addition of a nucleation agent or even injecting nuclei can activate the cooling process. Overall, the advantages of highly subtle salt hydrates, high temperature fluctuations, low volatility during melting, low toxicity and decay (associated with plastics), and are cheap when used in the purest form. The last category of non-living PCMs is metallics. Metallic is a molten metal that melts at low temperatures. They have a large volumetric capacity but due to high density; they have a low energy density. PCMs have high thermal conductivity, and therefore do not require the development of thermal conductivity. Another category is eutectic compounds. Eutectic compounds for 2 or more PCMs, which at some point, melt at room temperature. Functionality: Phase Changing Material is a material that absorbs and releases heat energy during melting and cooling. When a PCM freezes, it emits a lot of energy in the form of subtle heat at the same temperature. Conversely, when such substances melt they absorb large amounts of heat from the surrounding environment. PCMs are also charged as the ambient temperature fluctuates, making them suitable for a variety of daily uses that require temperature control. PCMs are designed to cover a wide range of temperatures from -40 ° C to over 150 ° C. They usually store 5 to 14 times more heat per unit volume than materials such as Water or Stone. Amid many heat storage alternatives, PCMs are attractive because they offer high-density energy storage and store heat within a narrow temperature range.

2.3 Air Cooling

Air cooling generally uses the principle of convection for transferring heat away from the battery pack. As and when the air runs over the surface of the battery, it carries with it the emitted heat by the surface. This technique of cooling is simple but at the same time not very yielding. Convection is a process in which bulk movement of molecules within gases takes place. At the beginning stage heat transfer between object and gas takes place through conduction, but the bulk heat transfer takes place due to the movement of the gas. When the battery gets heated thermal expansion takes place. The lower layer which is hotter becomes less dense. We know that colder part is denser. Due to buoyancy, the less dense, hotter part rises up and the colder dense replaces it. This process is repeated and hence the convection process is carried and the heat transfer is carried out. Convection is carried out by two types.

- Natural Convection
- Forced convection.

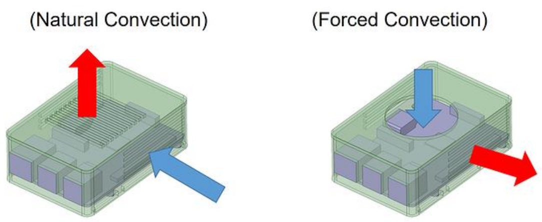

Fig.1 Types of Convection

1. Natural convection: When the convection takes place due to the buoyant force because of the difference in densities caused by the difference in temperature is called as natural convection. Example of this may be natural air.

2. Forced convection: With presence of external sources being used for creating convection is called as forced convection. These sources maybe externally accommodated fans or pumps. These similar types of process are also involved in the thermal management of electric vehicles where the vehicles maybe cooled with the help of natural air or with the help of fan.

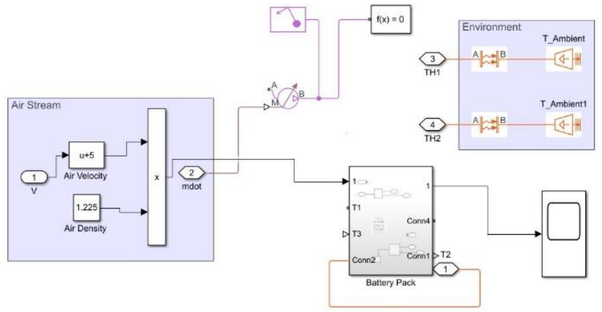

Fig.2 Thermal Management of Battery pack using Air Flow

Advantages: Air cooling system is less complex and has low application cost.
Disadvantages: Air cooling process cannot be used for most new high-performance applications due to the power density required and the wide range of ambient temperatures it needs to moderate. It is not possible to extract sufficient heat from the battery with the help of just the cooling system. Some cooling may take place inside the battery pack but that alone is not sufficient to bring down external temperatures to a moderate level. The fan for forced air extraction is big and it needs power from the battery to be driven which may result in large pressure drop.

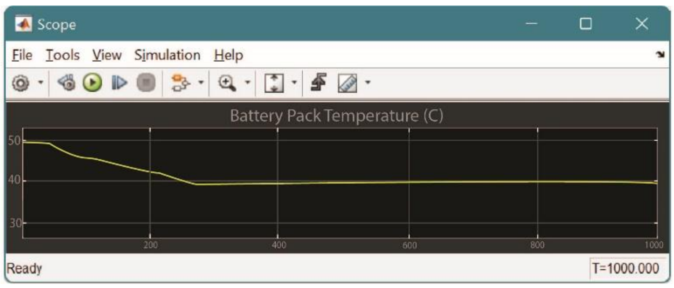

Fig.3 Temperature drop in Air Cooling System

2.4 Liquid Cooling

Liquid cooling has a high temperature and heat capacity so it works very effectively. It has its advantages such as ease of planning and compact structure. Liquid cooling helps to maintain the correct battery pack temperature. According to experienced researchers, liquid cooling is probably one of the most effective cooling methods compared to any other. A cold and warm microchannel model for a single type of liquid ion battery was developed by Zhao. Tong designed the BTMS based cooling fluid (battery temperature control system) for the bipolar Lithium-Ion battery pack. Medium temperature and temperature similarity can be improved by increasing the cooling flow rate or plate thickness. The cooling performance of any liquid will depend on its thermal conductivity and its viscosity. The main consideration of any cooling liquid is a certain temperature. Plain water has a very high special temperature although it cannot be used alone so it is mixed with glycol. Glycol is a substance of the alcohol family. It is also used with water to protect it from ad heat. Glycol blends with water are inexpensive and are a very stable cooling fluid. The mixture contains 50% glycol, 45% water and 5% additives, which may include antifreeze, corrosion inhibitor, dye and antioxidant. Glycol has a good specific heat capacity and has good heat transfer properties. Water-glycol systems are considered indirect cooling. Glycol pumping is done through pipelines around the battery. The supply of this water-glycol mixture is provided using supply pumps. BTMS uses liquid cooling, heat transfer is achieved by inserting a straight tube around the battery cells with a jacket around the battery cells placing the hot liquid or cooling plate in place of the battery cell or immersing the cells in dielectric liquid.

Glycol used can be of two types:

1. Ethylene Glycol (EG): - This is used as an antifreeze for cooling car engines.

2. Propylene Glycol (PG): - PG has the same benefits as EG. In addition PG is considered to be non-toxic as well.

Battery cooling can be divided into two types

1. Passive Cooling
2. Active cooling based on control strategies.

In random cooling the cooler is cooled with the help of air through a uniform flow heat exchanger while in effective cooling the cooler is cooled with the help of a refrigerator with an indoor heat exchanger. In idle cooling the cooling heat sink is a radiator. In cooling of a constant fluid the heat transfer fluid is transmitted through pumps inside a closed system. The circulating fluid will absorb heat from the battery pack and expel it through a radiator.

In effective cooling there are two traps. The lower loop is called the second loop and the upper loop is called the main loop. The main loop is similar to a loop in a cooling system, in which the heat transfer fluid is transmitted through a pump. The second loop in active cooling is an air conditioning loop. In this case the high temperature switch instead of the radiator acts as an evaporation cooler and connects both loops. When the heating function occurs, the 4-way valve will be replaced and the high temperature switch will start operating as a condenser and the low temperature switch will operate as a steamer.

There are usually two types of fluids used in system temperature control. First is a dielectric liquid also called a direct contact liquid that can directly contact battery cells, this includes mineral oil. Second is a continuous fluid also called indirect fluid that directly affects battery cells, this includes a mixture of ethylene glycol and water. A different structure is formed depending on the type of liquid. In direct contact liquid, the structure is usually immersed in mineral oil while in direct contact with a potential structure can be a jacket around the battery module, separate tubes around each module, placing the battery module on the cooling / heating plate or assembling the battery. cooling / heating modules and plates. Indirect communication systems are often preferred to find better separation between the battery and its surroundings.

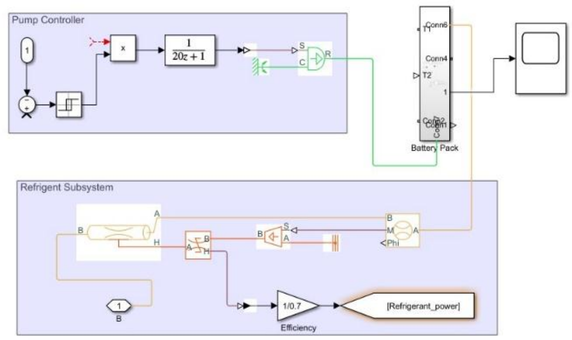

Fig.4 Thermal Management of Battery using Liquid Cooling

Advantages: Glycol cooling requires less energy compared to air cooling to maintain the same moderate temperature. It can withstand rust and operate over long distances. Greater cohesion and greater uniformity of temperature between cells. It has a higher cooling rate compared to the air conditioning system.

Disadvantage: Glycol loses energy over time. Not compatible with current composite chemistry. It also has potential concerns about power outages, according to a study by Afton Chemical. Any leakage in this way can be a major problem for the car. Liquid cooling is considered to be more complex than air cooling. This requires a lot of space and the weight of the car. The cost of this is high compared to the air conditioning system.

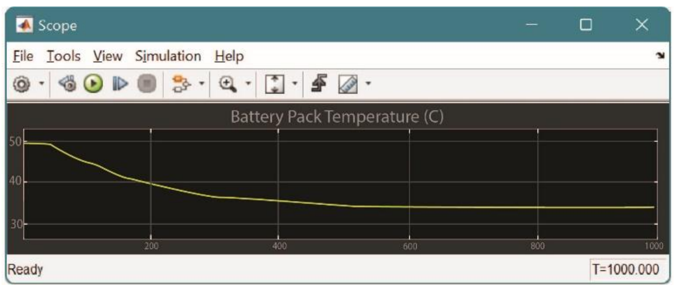

Fig.5 Temperature drop in Liquid Cooling System

2.5 Thermo-Electric Cooling

Thermoelectric coolers used in battery temperature control systems are relatively new technologies in the field of electric vehicles. Their advantages are strong cooling capacity and reliable performance and have gained the combined attention to the battery temperature control system. A major problem with air and water cooling is that the cooling effect can be very limited under certain conditions. A thermoelectric module is a solid state converter that contains a large number of thermocouples connected in series and in thermal coupling.

Functional: Thermoelectric cooler (TEC) is based on converting electrical energy into temperature differences. It refers to all the processes of conversion from heat to electricity and vice versa. It works according to the Peltier effect. The result creates a temperature difference by carrying heat between the two electrical outlets. A voltage is applied to the entire conductor combined to generate electrical energy. When the current flows into two conductors, the heat is removed from one of the peninsula and then cools. Heat is applied to the junction of the area. The key to the Peltier effect is cooling. Peltier effect can be used to heat or control temperature.

Thermoelectric electric cooling has fewer advantages than other cooling systems such as stationary device, no internal chemical reactions, no noise, long operation, no harmful emissions, and the cost of repairing it. The disadvantages of TEC are poor efficiency and the need for additional power that limits their commercial use.

Simulation Model Setup

We are using a Compression method for the TEC setup. Battery pack is sandwiched between cold plate and heat sink and packed with aluminum sheets for heat conduction. It is the most common & efficient way for TEC type cooling systems.

Battery Specifications

Lithium Nickel Manganese Cobalt Oxide (NMC) cells were used in our experimental Electric Vehicle. There are a total of 96 cells. The specification of NMC cells are as follows

Weight (g)	1580
Nominal Capacity (Ah)	75
Nominal Voltage (V)	4.2
Operating Temperature (°C)	-15 to 60

So the weight of the battery pack is around 151 kg with a total voltage of 403.2 V as cells were in series with each other. Total capacity of the battery pack is 75 Ah.

Battery's internal resistance

On the other hand, the battery's actual terminal voltage E_{emf} deviates from equilibrium electromotive force (electrode potential) due to electrochemical polarization of the battery. This process generates heat Q_p, which is the energy loss during polarization in the charge and discharge of the battery. $Q_p = I^2R$, where R_p is the polarization resistance that comes with polarization process. Finally, Joule heat Q_i is generated because of the internal ohmic resistance of the battery. The heat generated during the charge/discharge process is $Qj = I^2R_i$, where R_i is the internal ohmic resistance of the Li-ion cell.

Load Specifications

For our experimental electric vehicle we have Emrax 188 axial flux motor with the following specifications:

Top speed (km/h)	141
Peak Torque (Nm/sec)	50
Motor Type	Axial Flux Motor
Phase	Three phase AC
Nominal Motor Voltage (V)	150

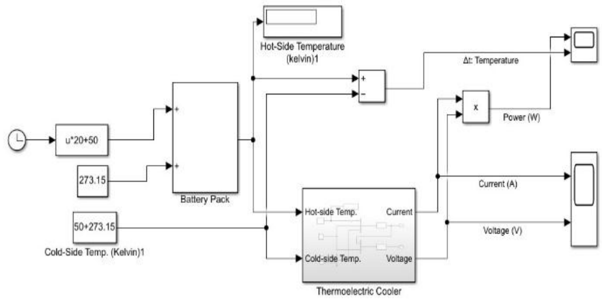

Fig.6 Thermal Management of Battery using Thermo-Electric Cooling

Heat balance

Equation (1) expresses the total amount of heat per unit time during the charge Q_{tc}, where I_c is the charging current, and (2) expresses the total amount of heat Q_{td} per unit time during discharge, where I_d is the discharging current. R_p is the polarization resistance that comes with polarization process & R_i is the internal ohmic resistance of the Li-ion cells.

$$Q_{tc} = -nFT\left(\frac{\delta E_{emf}}{\delta}\right) + (R_p + R_i)I_c^2 \quad \text{......................(1)}$$

$$Q_{td} = nFT\left(\frac{\delta E_{emf}}{\delta}\right) + (R_p + R_i)I_d^2 \quad \text{.......................(2)}$$

The values of the internal ohmic and polarization resistances depend on the depth of discharge (DOD) and the battery size. The manufacturer's values of the internal resistance are within 3-8 mΩ range

Heat Generation Rate

The thermal output power of the BTMS was evaluated by calculating the heat gained by the heat sinks and aluminum plates, while the heat gained by the air inside the battery box was neglected.

H= mcdT. where H is the heat gained (in J), the mass m = 51000 g , and c is the specific heat (c = 0.963 J/g ºC) of the heat sinks and the aluminum sheets. dT is the temperature differential (°C). Subsequently H = 49113 dT. The output power is then Q = 49113 dT/dt (W). Finally, the measured value of the COP is expressed in Eq. 4 where PIN is the input electrical power.

$COP_{Measured} = Q/(P_{IN})$

The analytical solution for the cooling capacity of the TEC modules obtained from the thermal model circuit is expressed in equation (3) & COP_{Model} is expressed in (4)

$$Q_{Battery} = \frac{2N\alpha I[T_c\theta - \Delta T(\theta_{TH}+\theta_{HA})] - NI^2R_e(2\theta_{TH}+2\theta_{HA}+\theta) - (T_A - T_{Battery})}{(\theta_{BT}+\theta+\theta_{TH}+\theta_{HA})} - \frac{(T_A - T_{Battery})}{(\theta_{SA}+\theta_{BS})} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$COP_{Model} = \frac{2N\alpha I[T_c\theta - \Delta T(\theta_{TH}+\theta_{HA})] - NI^2R_e(2\theta_{TH}+2\theta_{HA}+\theta) - (T_A - T_{Battery})}{(\theta_{BT}+\theta+\theta_{TH}+\theta_{HA})[2NI(\alpha\Delta T + IR_e]} - \frac{(T_A - T_{Battery})}{(\theta_{SA}+\theta_{BS})[2NI(\alpha\Delta T + IR_e]} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Symbol	Description
Θ_{BT}	Thermal resistance of the junction Li-ion cell/TEC (K/W)
Θ_{TH}	Thermal resistance of the junction TEC-to-heat-sink (K/W)
Θ_{BS}	Thermal resistance of the junction Li-ion cell-to-aluminum sheet (K/W)
Θ_{HA} = 0.0168	Thermal resistance of the heat-sink + blowers (K/W)
Θ_{SA} = 0.0132	Thermal resistance of the aluminum sheet (K/W)
K	Thermal conductance of the TEC (K/W) θ = 1/2 N
N = 186	Number of the couples
I	Input current (A)
α = 0.01293	Thermoelectric coefficient (V/K)
Re	Electrical resistance of the TEC module (Ω)
V	Input voltage (V)

Application: A thermoelectric cooler converts heat into electricity and vice versa. The TECs application revolves around two main features namely converting heat to electricity and electricity to heat. There are many uses of TEC. The main use of TECs is their use in cooling Li-Ion batteries, a state-of-the-art computer microprocessor and building an air-conditioning system. TECs have also recently been used in portable refrigerators, portable air heaters and car cooling. Promising use of TECs to integrate with PCMs so that BTMS can make the passive system a semi-passive system and thus increase the efficiency of BTMS.

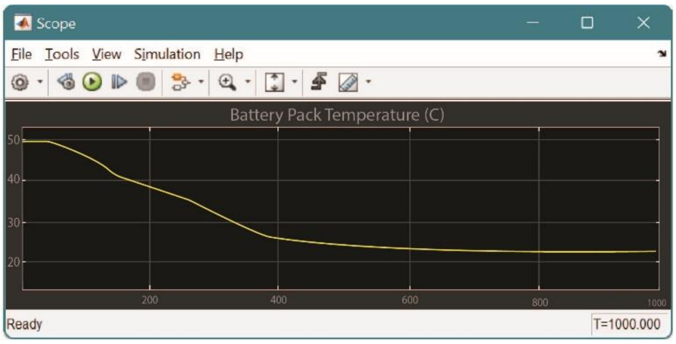

Fig.7 Temperature drop in Thermo-Electric Cooling System

3. Comparison between Air/Liquid/Thermo- Electric Cooling

Based on repetitive analysis of the above mentioned cooling systems, we can observe that the Thermo-Electric cooling system yields out maximum reduction in battery back temperatures followed by liquid cooling system and air cooling system. The simulation was done on MATLAB considering real life conditions.

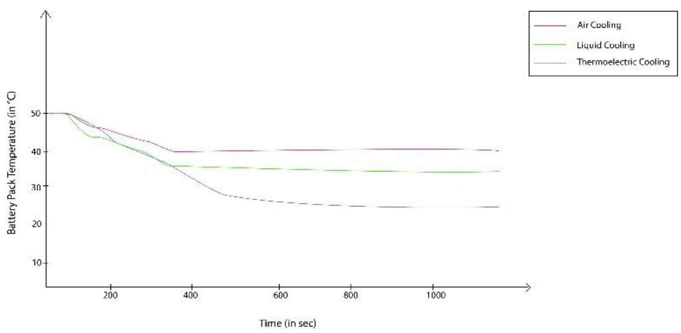

Fig.8 Comparison of different Thermal Management system for Battery Pack

4. Emerging Smart Technologies in Cooling

New cooling technologies are paving their way into making the cooling system for electric vehicles cost efficient and performance oriented. After undergoing extensive research practices, some modern cooling technologies have emerged which are as follows:

4.1 Cabin Air Cooling

Interaction between powertrain and cabin thermal-management systems is one of the novel aspects of electric cars. This technology works with the preconditioned air in the cabin of the vehicle which provides an external aid to the cooling of the battery and proves to be an efficient way of improving thermal stability. Further it has found usage in speeding up fast power charging.

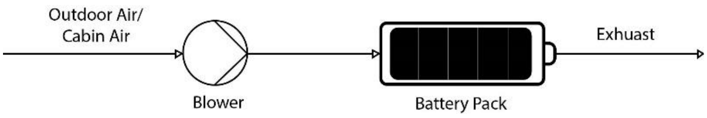

Fig.9 Cabin Air Cooling

4.2 Independent Air Cooling

This system follows similarity to cabin air cooling. It consists of an evaporator that removes heat from the battery. Refrigerant gets evaporated at low temperature and absorbs heat. Thus, battery gets cooled below cabin temperature.

4.3 Direct Refrigerant Cooling

The direct refrigerant connects an evaporator plate in parallel with the current evaporator of vehicle air condition. Evaporator plates have direct contact with the battery plate.

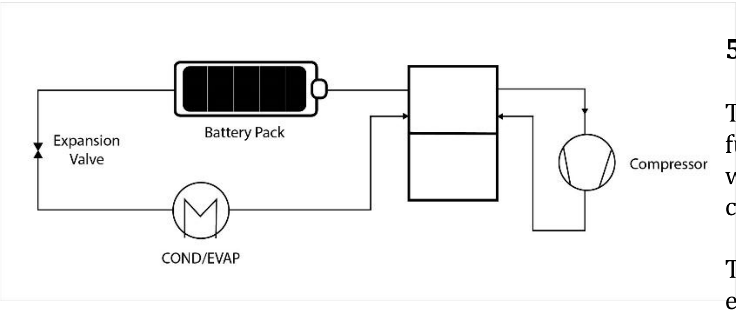

Fig.10 Direct Refrigerant Cooling

4.4 Heat Pipe Cooling

It is yet another proven emerging milestone in the cooling system of electric vehicles. The heat pipe is an envelope of pipes having a capillary powder structure with sintered copper powder. It is used as an evaporator which absorbs heat while operation and dissipates heat in the condenser and becomes liquid again., In comparison to thermo-electric, a heat pipe is more reliable, because there are no moving parts and no energy consumption. However, a heat pipe is unable to heat the battery due to its fixed structural layout.

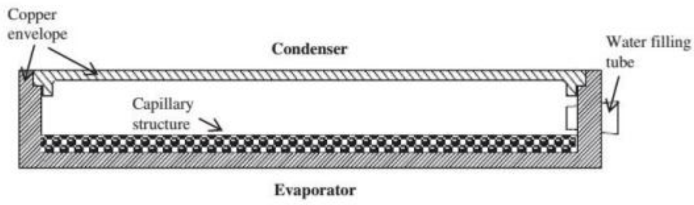

Fig.11 Heat Pipe Cooling

4.5 Combinational Liquid Cooling System

This system has four modes: bypass with heater modes, passive cooling and active cooling. Passive cooling is most preferred as it has simple construction and low power usage.

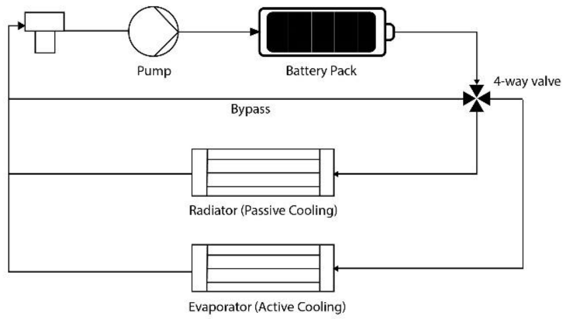

Fig.12 Combinational Liquid Cooling System

5. Conclusion

The rapid usage of the EV is going to increase in the near future as sustainable transport is concerned and due to which the need for development of an efficient battery cooling system are priority.

This paper proposes on various battery cooling techniques of electric vehicles. A detailed explanation and analysis of Air cooling system, Liquid cooling system and Thermo-Electric cooling system was done. Temperature drop comparison of the latter is also done on MATLAB and a graph was obtained. Of all systems compared in the analysis, the Thermo-electric Cooling proved to be the most efficient and significant drop in battery temperature is noted. Some emerging technologies in the field of cooling systems for electric vehicle have been briefly discussed. These technologies are proving to become sustainable and efficient in cooling systems and thus provide better thermal management. The methods and systems discussed provide a performance oriented and cost efficient solution to the issue of thermal management in battery.

6. References

1. Zhao, R Zhang, S Liu and Gu J 2015 A review of thermal performance improving methods of lithium-ion battery

electrode modification and TMS Journal of Power Sources 299

2. T M Bandhauer, S Garimella and T F Fuller 2011 A Critical review of thermal issues in lithium-ion batteries, J.Electrochem. Soc., 158 R1-R25

3. Karimi, G.; Azizi, M.; Babapoor, A. Experimental study of a cylindrical lithium-ion battery thermal management using phase change material composites. J. Energy Storage 2016, 8, 168–174.

4. J. Pereira da Cunha, P. Eames, Thermal energy storage for low and medium temperature applications using phase change materials - A review, Appl. Energy 177 (2016) 227–238.

5. A. Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, Review on thermal energy storage with phase change materials and applications, Renew. Sustain. Energy Rev. 13 (2) (2009) 318–345

6. C. C. Chan and K. T. Chau, Modern Electric Vehicle Technology, Oxford University Press, Oxford, UK

7. J. Larminie and J. Lowry, Electric Vehicle Technology Explained, John Wiley and John Lowry, England, UK

8. Lyu, Y., Siddique, A. R. M., Majid, S. H., Biglarbegian, M., Gadsden, S. A., & Mahmud, S. (2019). Electric vehicle battery thermal management system with thermoelectric cooling. Energy Reports, 5, 822–827. doi:10.1016/j.egyr.2019.06.016