J Inno Sci Eng 2017, 1(1): 35-55

Review of Batteries Thermal Problems and Thermal Management Systems

K. Furkan Sökmen[1*], Muhammed Çavuş [2]

[1]*Bursa Technical University, Department of Mechanical Engineering, 16310 Bursa, Turkey*
[2] *Bursa Technical University, Graduate School of Natural and Applied Sciences, 16310 Bursa, Turkey*

Abstract

Electric vehicles, lithium-based batteries that are used in solar energy storage are known from these products. Especially, in electric (EV), hybrid (HEV) and fuel cell vehicles (FCEV), battery technology has been an important contributor to reducing toxic gas emissions and using energy efficiently. In this study, we have examined some of the problems with associated solutions for battery heat management and what information is needed for proper design of battery heat management. Later we have examined the types of batteries which are used in electric vehicles and the characteristics of these batteries. We have mentioned about battery thermal management varieties such as air cooling, liquid cooling, phase change material (PCM), thermoelectric module and heat pipe. Finally, we have provided information on the shape of the battery pack and the thermal management effect of the battery packing.

Keywords: Electric vehicles, Hybrid electric vehicles, Fuel cell electric vehicles, Phase change material

1. Introduction

In the automotive sector, the use of petroleum and derivatives as an energy source, has become a source of various economic problems as it is the main source of problems such as air pollution and toxic gas emissions. Car manufacturers, who are trying to develop under the pressure of environmental pollution and energy shortage, have begun to change the way of looking at the storage of energy, that is, the power of green energy, into clean energy vehicles. As a result of research and development activities, automotive industry, electric vehicles and depending energy storage products began to show interest in batteries [1]-[4]. Thus, the automotive industry have launched to reveal cleaner products and more energy efficient products with hybrid electric vehicles (HEVs), which can be hybrid vehicles charging from external sources (PHEVs), fuel cell electric vehicles (FCEVs) and battery-assisted electric vehicles (BEVs) [5–19]. There is an internal combustion engine next to the electric motor in a hybrid vehicle. The system charging vehicle movement or braking, can also be charged from external sources in PHEV vehicles. Following the use of the two combined energy systems, FCEV vehicles were produced which run with fuel cell. The fuel cell which is in these vehicles generates electricity energy by using hydrogen and oxygen. In recent years, battery-powered electric automobiles have become increasingly widespread [20,2,21]. The result of the accomplished researches and tests has been found as to be determined by the performance of batteries and battery modules of electric vehicles. In electric vehicles, battery safety, operating in harmony with each other in the battery module and operating in the proper temperature range, are the main problems and research points. As expected, the development of the life and power performance of batteries are very important for electric vehicles [22]. To improve the performance of electric vehicles, it is stated that they need batteries with a wide operating temperature range and high-current discharge systems. These batteries in the quick acceleration times, at high current levels, due to a variety of chemical and electrochemical reaction, produces heat during charge and discharge cycles. Another factor that increases the battery temperature, is the temporary regenerative energy recovery that occurs due to the mechanical movements of the vehicle during braking. During this process, the temperature of the battery rises again [23]. All of these changes have been realized to be an obstacle to the stabilization of the cells. Many studies have shown that the parameters of variation should be controlled [24–30]. It has been determined

[*]Corresponding author: Tel: +90.224.3003555 E-mail: furkan.sokmen@btu.edu.tr
Received 29 September 2017; Accepted 22 November 2017

that in a battery pack, from the module to another module, the temperature and the temperature difference outside the allowed values, lead to different charging / discharging behaviors in the battery. As a result, it has been shown that this negativity reduces the package performance caused by electrically unbalanced packages / modules and negatively affects the life cycle of the cells, which shortens the life and range of the vehicle [31,32]. Therefore, it has been stated ideally that batteries should operate at optimum temperature ranges for their performances and lifetimes. The desired operating temperature range, differs for different battery types (electrochemical aspects). Generally, the optimum operating temperature range of the battery is determined by the battery manufacturers. For example, for a lead acid battery, the desired temperature is between 25 ° C and 45 ° C, while in specific vehicles the operating range may be between -30 ° C and 60 ° C [33].

It has been demonstrated that the thermal management system for lithium-ion / polymer-based batteries, which can generate high temperatures, must be an integral part of the battery pack and should be incorporated into the design by battery packers. Shortly, regardless of the battery type; Lead acid, Ni-MH and Li-Ion batteries require a successful thermal management system because of the main problems such as proper heat dissipation and thermal leak safety [22]. Today, EV and HEV batteries are manufactured with a thermal management system [23,33,34].

In order to overcome the problem of battery thermal management, in previous studies heat transfer and fluid mechanics basic principles and computational fluid mechanics have been used [35–37]. Thermal imaging techniques, thermocouple measurements are used as experimental devices to detect battery thermal distribution [31,35,37,38]. Especially, with computational fluid dynamic solutions (CFD), thermal distribution of batteries can be determined, and required design modifications are made before package design is finished [39]. The increase in temperature in the battery can lead to undesired conditions such as burning and explosion. For this reason, it has been demonstrated that the impact resistance, combustion analysis for battery and battery pack should be conducted by CFD and finite elements method [40,24].

The thermal management of the batteries can be accomplished with an electric fan system basically, as well as thermal management systems which use air or liquid for thermal management. Glycol, oil, acetone and even other known refrigerants are used in thermal management systems. In addition to these, heat pipe and especially PCM (Phase Change Material), which has recently become widespread, are used for battery thermal management systems. Although PCMs have high temperature storage capacity, they have low thermal conductivity. PCM materials such as paraffin wax are not effective at high temperatures. Several methods have been investigated to solve the disagreement between high thermal storage capacity and low thermal conductivity. The aim is to increase the thermal conductivity of the PCM. During operation, it is also important to capture the balance and obtain a powerful battery that will resist thermo mechanical effects [22].

This is a comprehensive review of the thermal management of batteries which are used in electric vehicles. From battery thermal management systems, applications of air, water, FDM, thermoelectric and heat pipes have been examined in detail. Also, a comparison of the thermal conductivity coefficients of PCM materials is included in the study. We hope that this study will be beneficial to our country's electric vehicle sector, academia and researchers.

2. Batteries Used in Electrical Vehicles

In general terms, in terms of historical development, lead acid, nickel-based zinc / halogen, metal / air, sodium beta and lithium-based batteries in automobiles are rechargeable power sources that were used for EV and HEV.

In addition, it is noted that lithium-based lithium manganese oxide ($LiMn_2O_4$), lithium iron phosphate ($LiFePO_4$), and lithium nickel manganese carbon oxide ($LiNiMnCoO_2$) batteries are among the battery types that are available for EVs. From these batteries, lithium-ion batteries types have been widely used in recent years [4]. Li-ion batteries are more costly than other batteries. This is an obstacle for electric vehicles in terms of practicality [41,42].

In the early 1990s, lead acid-based batteries, due to being low cost and having specific power characteristics, were short-lived in the face of developing technology. Despite having the short life span, in order to improve the performance of lead acid based batteries, various studies and research and development activities have been carried out [43–45].

Compared to lead acid batteries, Li-ion batteries have a longer life, and higher energy capacity. It has been reported that the energy capacity of Li-ion batteries is 3 times higher than Ni-MH batteries and 2 times higher than lead acid batteries. It has been realized that in terms of volume, Li-ion battery packages are smaller and lighter compared to nickel metal hybrid (NiMH) battery packages. Li-ion cell-based batteries have been use in commerce for decades since it was invented by the Japanese company in 1991. In terms of performance and life, Li-Ion batteries which have high standards, have entered the automotive sector, taking the place of nickel-based battery packs in the industry. It has begun to be used widely in EV and HEV industry [46–52].

The obtained results from the investigations on typical characteristics of the batteries used in EV and HEV, are shown in Table 1. It is seen from this table that in terms of energy and power, Li-ion battery has better performance than others [22].

Table 1. Typical characteristics of EVs and HEVs power batteries [33]

	Reference (s)	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Specific Power (W/kg)	Cycle Life (Cycles)
Lead-Acid	[41]	30-50	60-100	200-400	400-600
Lead-Acid	[46]	48			800
Ni-Fe	[41]	30-55	60-110	25-110	1200-4000
Ni-Zn	[41]	60-65	120-130	150-300	100-300
Zn-Air	[41]	230	269	105	
Ni-MH	[53]	80		1000	
Li-Ion	[47]	93	114	350 (50 %)	
Li-Ion	[54]	94.8			4000
Li-Ion	[53]	120-130	200-300	1500	
Li-Ion	[55]	150	300		1000
Li-Ion	[56]	150-200	460-600		8-10 years

3. Heat Problems in Battery

In case of charging / discharging in batteries, various chemical and electrochemical reactions take place [24]. Especially, at high current levels during rapid charge-discharge and low-to-high voltage batteries produce more heat than normal case. The generated heat depends on the chemical form of the cell, structure, state of charge and charge / discharge profile. Increasing the size of the battery pack and increasing the number of cells can cause severe heat and electrical imbalance problems [25, 28, 54-57].

To achieve a proper balance between performance and lifetime, it has been demonstrated that the optimum operating range for Lead Acid, Ni-MH and Li-ion batteries is between 25°C and 45°C and the temperature difference should be maximum 5°C from module to another module [30]. Namely, It is desirable that the temperature is stable so that there are small changes between cells [61]. On the other hand, in previous studies on lead-acid it is stated that, the temperatures between -26°C and 65°C are suitable in terms of productivity and power capacity [62]. In another study, li-ion batteries are required to have a maximum operating temperature of between 45ºC and 50ºC and It is desirable to come down to temperatures below -10ºC in terms of life and safety [63]. Temperature affects batteries in 5 important ways [64]:

1. It can disrupt electrochemical operation principle.
2. It extends efficient charging and depending on this, extends charging time.
3. It reduces energy efficiency.
4. It affects safety and reliability negatively.
5. It shortens the life span and requires maintenance [64].

As a result of the analysis, it is seen that there are two main problems that arise from the temperature. One of them is, heating that occurs during the charge and discharge; this affects negatively the life of the vehicle and battery. The second is the uneven distribution of temperature in the battery pack; which leads to disturbances in battery construction and among modules [65].

The heat values have shown that under certain conditions, different cell types produce in charging and discharging states in experiments in Table 2. As it can be seen from Table 2, at 40ºC - 50ºC, electrochemical reactions can be endothermic (received heat) during discharging of Li-ion battery. In addition, it has been observed the Ni-MH batteries, at high temperatures (≥40ºC) during the charge / discharge when compared to lead acid batteries and Li-ion, produce higher temperatures. It is seen that an increase in result of the discharge capacity in the battery types increases in the produced heat in Table 2.

Table 2. Heat generation from Typical HEV/EV Modules using NREL's Calorimeter [66,67]

Battery Type	Cycle	Heat Generation (W) / Cell		
		0ºC	22-25 ºC	40-50 ºC
VRLA 16.5 Ah	C/1 Discharge, 100% to 0% State of Charge	1.21	1.28	0.4
VRLA 16.5 Ah	5C Discharge, 100% to 0% State of Charge	16.07	14.02	11.17
NiMH 20 Ah	C/1 Discharge, 70% to 35% State of Charge	-	1.19	1.11
NiMH 20 Ah	5C Discharge, 70% to 35% State of Charge	-	22.79	25.27
Li-Ion 6 Ah	C/1 Discharge, 80% to 50% State of Charge	0.6	0.04	-0.18
Li-Ion 6 Ah	5C Discharge, %50 to %80 State of Charge	12.07	3.50	1.22

It has been noted that lead-acid batteries cannot be charged at temperatures below 0°C [68]. Most scientific studies on battery thermal management concern most of the problems that li-ion batteries have at high temperatures [65]-[75]. The results of these studies on Li-ion batteries have found that both performance and energy storage are significantly reduced at temperatures as low as -10°C. In another study, it was noted that lithium-ion batteries are highly efficient in energy storage, but their performance is noticeably reduced at -30°C [80]. If the battery temperature falls to very low temperatures, such as -30°C, it is stated that the battery must be heated quickly [33]. Moreover, although charging is very difficult at low temperatures, it has been found that the discharge can be performed normally [79,81,82].Cells could not efficiently operate at low temperatures. To give an example, the 2012 Nissan Leaf vehicle can go 138 km and but at -10ºC environmental conditions it could go 63 km [74,83]. In Figure 1, it is seen that the power of li-ion batteries reaches to the worst values at high and low temperatures. In addition, li-ion battery reaches a maximum power in the range of 20°C to 40°C [84]. In Figure 2, li-ion batteries show problems that may occur due to voltage and temperature.

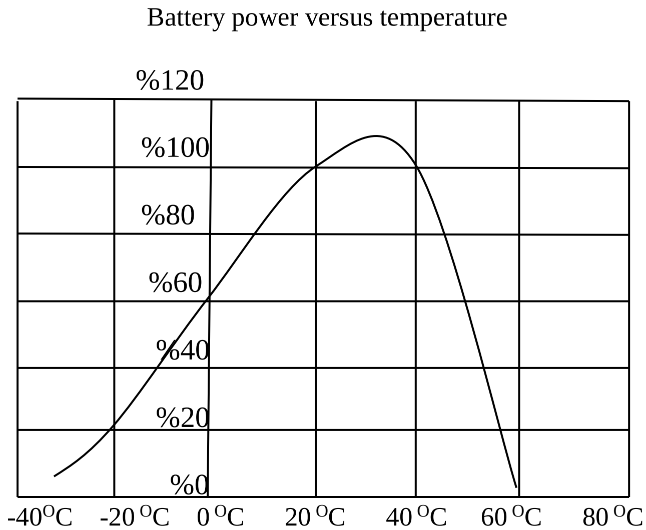

Figure 1. Battery power and temperature [84]

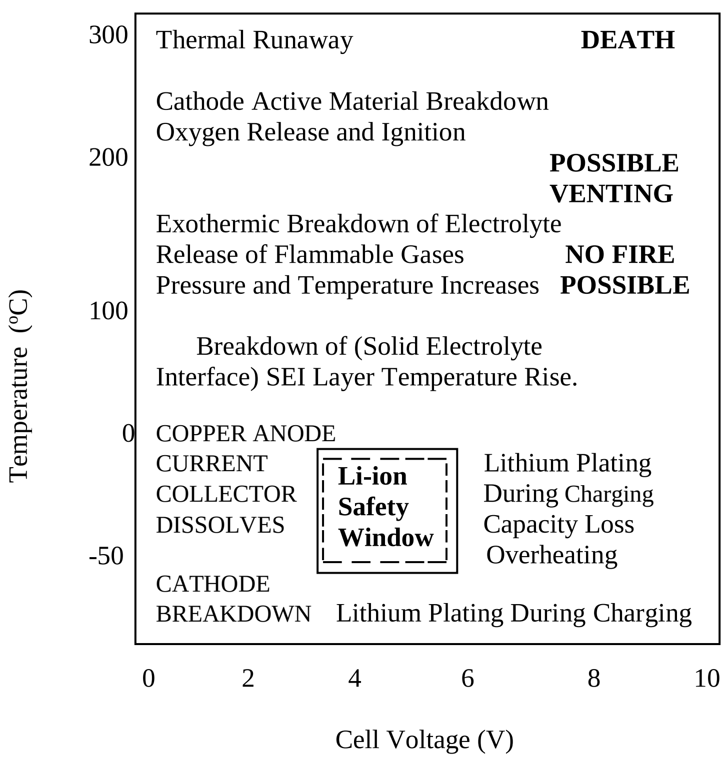

Figure 2. Li-ion batteries show problems that may occur due to voltage and temperature [85]

Basically, the reason of weak performance of Li-ion batteries at temperatures lower than 0°C has been found as due to the stabilization of the chemical molecules in the cell, the weak electrolytic conductivity, the decrease of the lithium movement in the cell and the increase of internal resistance [69,70,81,86,87]. As can be seen from Figure 2, it has been seen that charging the battery too far below 0°C causes to breakdown of the end of the cathode and short circuit [85]. However, the more appropriate electrolyte, the more use of some carbon-based solvent will increase the resistance to freezing or heating which can reduce the impact of the problems. With electrolytic salts that raise solvent additives and freezing point, it is indicated that batteries can operate at -60°C [60,74].

4. Desired Attributes of a Thermal Management System

The choice of the battery temperature management system is an important parameter that affects the life and performance of the electric vehicle [88]. The aim is to achieve a regular temperature distribution among the cells, by taking into account battery life and performance and by the battery manufacturers who determines the optimum average temperature. Thermal management system must meet the requirements which are specified by the vehicle manufacturers. The thermal management system to be installed should allow the use of the package under different climatic conditions (from extreme temperature to extreme cold) and ventilation should be provided if the battery produces potentially toxic gas. The main features required from the battery thermal management system are as follows [22,89,90].

1. Each cell and battery system must be kept at the optimum temperature range and the heat it receives must be able to transfer to the cold environment properly.
2. Temperature changes should be minimized in each cell.
3. There should be no sudden temperature changes throughout the system and these changes should be minimized.
4. The thermal management system should be easy to set up and maintain, and the service cost should be cheap.
5. If harmful gases occur in the battery, the system should be able to remove it.
6. The battery pack should have as little load as possible.
7. If temperature management requires the use of refrigerant, leak proofing must be provided.
8. The materials to be used in the thermal management system must be electrically isolated [33,64].

5. Designing Battery Thermal Management Systems

First of all, to establish an acceptable thermal management system, it is necessary to determine the temperature analysis and the heat load of the package under normal conditions. For this, the heat capacity of a cell must be known [22]. The design and installation of the battery thermal management system depends on many parameters. These parameters depend on factors such as the level of complexity of the system, applicability and budget [36]. The steps to follow for Battery Thermal Management are:

1. In the first stage, the design and limits of the battery temperature management system should be defined. In this article; requirements such as battery shape, accepted maximum-minimum temperature values, accepted temperature difference are considered.
2. The heat production and the heat capacity of the battery pack are obtained by testing and analyzing. These investigations affect the magnitude of the cooling / heating systems and determine detail of the temperature changes.
3. The results of the analysis and the tests, determine the thermal management system to be installed in accordance with the results which were obtained. Initial analyzes were done to determine the condition of the module and the package in short-term and stagnant air. To design a good battery thermal management system, it is recommended to start with packaged batteries, and high heat transfer coefficient material.

4. With detailed analyzes, the temperature distribution in the system, determination of consisting the cells of the maximum temperature, determination of risky areas are performed.
5. Together with the identification of risky areas, the prototype of the preferred thermal management system should be tested.
6. According to the results obtained, the thermal management system can be changed or if appropriate result is obtained improvement can be preferred [91–93].

6. Battery Thermal Management Systems

Choosing the proper battery thermal management system has a significant impact on battery cost and performance [94].

6.1. Air Cooling / Heating

Air cooling and heating is a widely used thermal management system. The air can be taken into the system from the outside or from the vehicle cabin. The air taken from the cabinet can be withdrawn from the evaporator or condenser. Thermal management with air can be an active system in passive system. While active systems need an external power source, compared to active systems, this power is very low in passive systems [94]. Cooling / heating can be performed by direct or indirect air flow from environment to the module (Figure 1). In air-cooling, the fin can be used to improve heat transfer by using the cooling plate. Huo and his colleagues [95] provided a temperature decrease on the battery with cooler plates wrapped around the battery. It has been determined that the number of plates is increased and the temperature falls. The change in flow direction was not very effective on the battery temperatures, but the rate of air entering into the batteries affected the cell temperature more [95]. In general terms, for air cooling / heating, 2 methods are used. The first method is series cooling. During series cooling, air enters one end of the package and leaves the other end: air will enter into the system channel and then will exit from another system channel. The second method is parallel cooling. The same total airflow rate is divided into equal parts in the opened channels and each part flows in a single mode. Depending on the geometry and size of the modules, series-parallel combination can be adjusted. In the parallel air flow, a more stable temperature distribution is observed between the modules in the package [31,36]. Xu and He have performed a practical work in a sample study, in the package cooling by positioning the battery pack vertically and parallel to the flow and also changing the position of the air inlet and outlet vents. As a result of the study, it has been found that effective cooling is not only dependent on air flow in the package but also on the structure of the air flow channel. It has been stated that opening the ventilation duct on both sides of the package with forced flow, makes the package cooling more efficient. In such a package design, it has been found that the flow of air in the pack increases the charge rate of the batteries. This rate is given as 70% occupancy. Under the same conditions, battery temperatures and changes are minimal [96].

The example forms of the air cooling process are given in Figure 3 [22]. In Figure 3, battery thermal management is performed with a simple air vent by using outside air or cabin air. The best examples of these systems are Honda Insight and Toyota Prius. In these vehicles, cabin air is used for heating and cooling. Figure 3 also shows the thermal management system which uses the evaporator or condenser in the air conditioner of the vehicle. Because the cabin air is heated and cooled by the car air conditioner, the system is known as active thermal management. In the passive thermal management system, it is stated that the ambient air must be between 10-35oC. Outside these conditions at temperatures, active components such as evaporators, motor coolers, and even electric or internal combustion heaters may be needed [23]. If the battery temperature rises above 660oC, it will be difficult to reduce this temperature below 520oC with air cooling. Also, at higher discharges and temperatures above 400°C, air cooling is not suitable. In this case, the temperature distribution will be irregular and interference with the battery surface will be difficult [97].

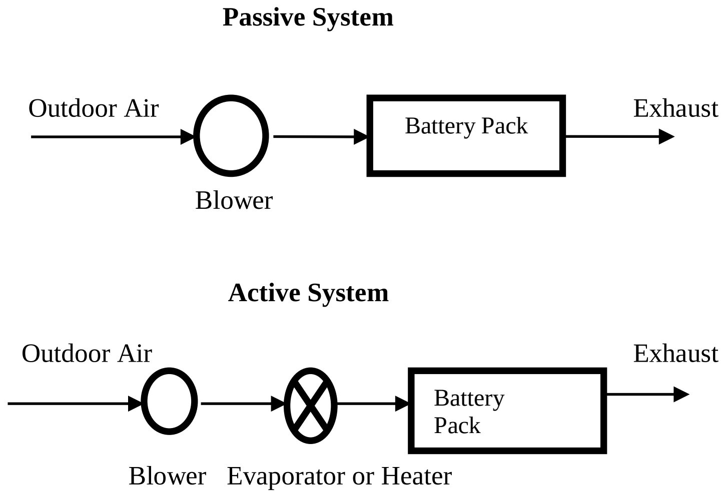

Figure 3. Forced air systems (passive and active)

As an example of the passive system, it is seen that hot air is directed to the battery pack by heat recovery from the exhaust air shown in Figure 4.

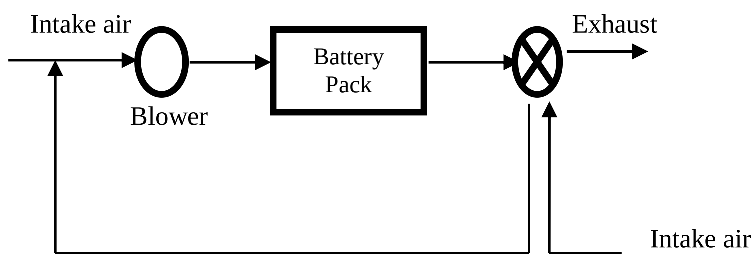

Figure 4. Forced air system with heat recovery

6.2. Liquid Cooling / Heating

Two groups of fluids are used in fluid temperature management:

1. Non-electrically conductive fluids: Fluids that are in direct contact with the battery. Example: Mineral oils
2. Electrically conductive fluids: Fluids that come into indirect contact with the battery with the mixture of ethylene glycol or water [84,98].

In the direct contact management system, the battery module is immersed in the liquid, while in indirectly contacted fluids; the battery block is left in the fluid in a sheath / jacket. With liquid thermal management, indirect heating and cooling can also be carried out by means of an intermittent pipe system around each module, with a channel or a pipe system which the liquid can circulate around [22,84,99]. In Jin's study [71], temperature stabilization was provided by flow of liquid from small channels in plates which were placed among cells [71]. In liquid thermal management, another application was made with oil. In a patented oil cooling application provided that the bodies are soaked in oil so as to be contact with the oil. Cooling oil is 1.5-3 times better than thermal control air. Thermal management is performed with solvents such as water or water / glycol and by indirect connection to be provided with a more efficient than oil cooling [22].

In thermal management with liquid, the management which made by indirect contact is more preferred. The reason for preference is expressed as better isolation with environment of the battery modules in the indirect system and better safety conditions. In passive thermal management with liquid, the vehicle radiator works like a cooling fin system. While the fluid is running in a closed system, as shown in Figure 5, the heat which takes from the battery pack removes from the radiator to outside. The disadvantage of this system is that the efficiency of the system decreases when the ambient temperature is high [84,100].

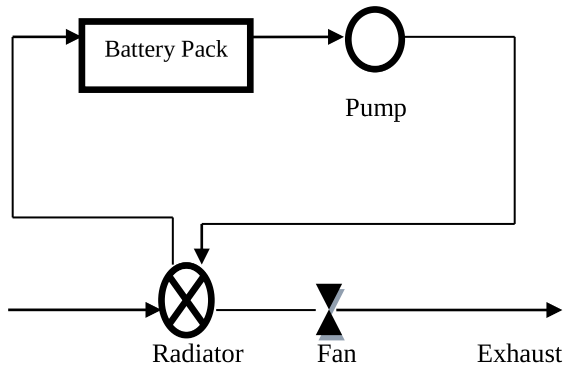

Figure 5. Passive liquid cooling system

Examples of active thermal management system with liquid are given in Figure 6. Such in temperature management system, there are 2 cycles. The first cycle is warming / cooling the battery, and the second cycle is the cycle of the car's air conditioning system. In the passive cooling system, the radiator is replaced by the condenser or evaporator of the air conditioning system in the active system. The system is capable of heating and cooling cycles with four-way valves.

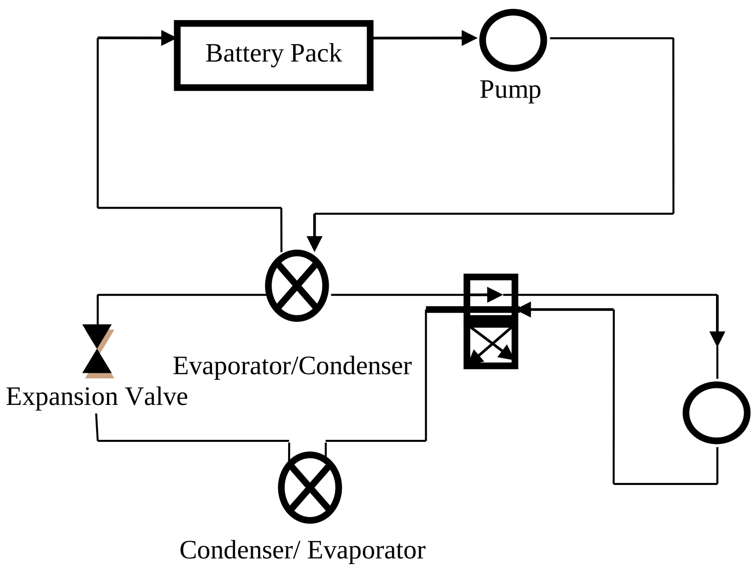

Figure 6. Active liquid cooling system

In the thermal management of the batteries, another active management method is to heat / cool the battery that is shown in Figure 7 by direct cooling fluid circulation. This system performs thermal management by heating and cooling with four-way valve.

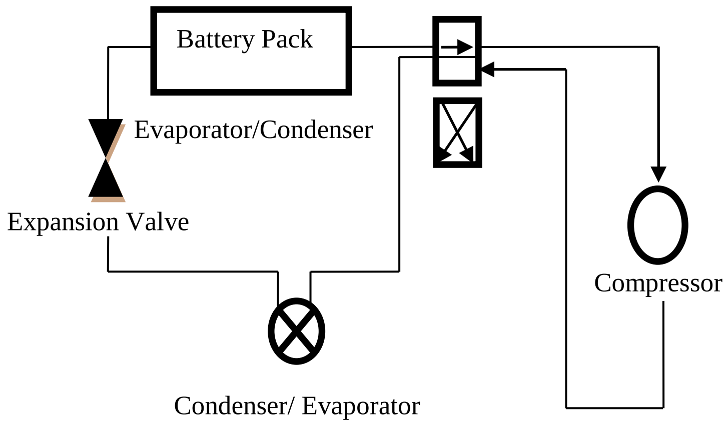

Figure 7. Direct refrigerant cooling system

6.3. Temperature Management with Phase Change Material (PCM)

An ideal thermal control system must be able to remain at the optimum temperature of the battery pack and low volume. The entire system of forced air and water heating / cooling consists of blowers, fans, pumps, pipes and other equipment (Figure 8). As a result, the battery pack becomes bulky, complicated and expensive [21]. Therefore, alternative thermal control solutions are needed. One of the original solutions which are developed to solve this problem is the use of PCM [101].

Phase Change Materials (PCM) are ideal products for thermal management solutions. Phase Change Materials (FDM, Phase Change Material) are substances that store the thermal energy as latent heat [102]. It has been stated that FDMs, used in applications, must have high latent heat, thermal conductivity, specific heat capacity and small volume change in order to be ideal. They should also not be corrosive and toxic and should not exhibit overcooling properties [103]. In order to use PCM for battery thermal control, firstly, it has been reported that they should be at a suitable melting temperature range [104].

The PCM material stores the sensible heat from the battery as latent heat and absorbs the temperature that is formed on the cell. During this process the PCM material is solid. The confined latent heat turns into liquid and emits as sensible heat. With this feature PCMs are used for the thermal energy storage [105,4]. The battery thermal management system with PCM was first demonstrated and patented by Al-Hallaj and Selman [106].

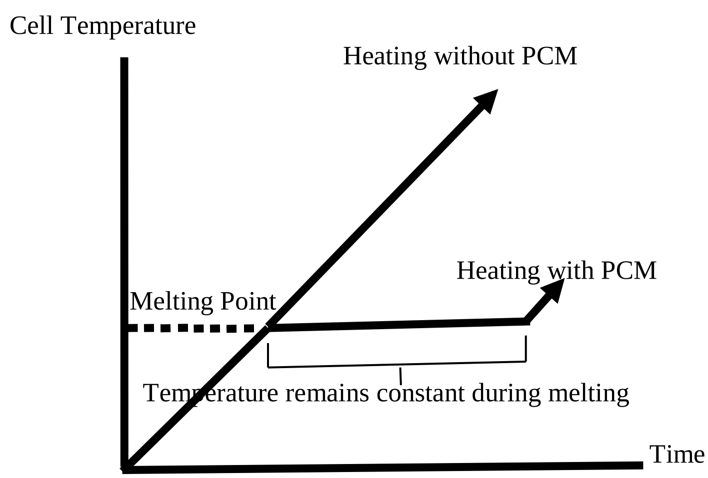

Figure 8. The working mechanism of PCM on battery cells [107]

Choosing the right PCMs for heating and cooling is key to an effective thermal management. The main criteria for PCM selection for thermal control are [108–110]:

- Having a melting temperature in the range of operating temperature,
- High latent heat, high specific heat and thermal conductivity,
- Small volume during the phase transition,
- Less or zero sub cooling during freezing,
- Not being irregular, toxic, flammable and explosive,
- Being lost costly while it is in high quantities.

For example, paraffin oil is composed of straight chain alkenes. These are chemically stagnant and demonstrate small volume changes of the below 500ºC and molten material having low vapor pressure. With these properties, paraffin can be regarded as PCM [110]. Conventional PCMs such as paraffin; it is seen as promising because of having the non-toxic, the corrosive nature exhibit and cheaper costs.

However, pure paraffin has problems due to its low heat transmittance and low heat storage capacity. High thermal conduction PCMs are great need for the battery thermal control. Khateeb et al. [101] has attempted to reduce the temperature increase of Li-ion cells by using aluminum foam with PCM. In the study, they indicated that the temperature drop of batteries provided a 50% improvement with the using of aluminum foam PCM [101]. From the results of the experiment, it was observed that as the percentage of paraffin increased, the tensile-stress properties increased at room temperature but the fracture toughness decreased [111]. In another study, Sabbah et al. [112] revealed that PCMs can operate at ambient temperatures as high as 45°C -50°C and cell temperatures do not exceed 55°C. In order to solve the contradiction between the large thermal storage capacity and the low thermal conductivity, it is recommended to select composite PCMs. In several studies, the thermal conductivity of some PCMs has been determined and given in Table 3 [33].

Table 3. Ideal PCMs in battery thermal management [104].

Reference	Method	PCMs	k (W/m^2K)	Latent heat (kj/kg)	Melting range (ºC)	Specific heat (kj/kgK)
[21]	Simulation Experiment	PW	0.21/0.29	195	40-44	1.77
[101]	Simulation Experiment	PCM/AF	-	-	-	-
[113]	Simulation	PW	0.12/0.21	173.4	46-48	289
[65]	Simulation	PW/Graphite	16.6	123	42-45	1.98
[32]	Simulation	PCM/Graphite	16.6	181	52-55	1.98
[51]	Simulation	PCM/Graphite	16.6	185	42-45	1.98
[114]	Simulation	PCM/EG	16.6	127		1.98
[115]	Experiment	PCM/EG	4.0-26	-	55	-
[111]	Experiment	PCM/EG	14.5 (12 s)	-	-	-

EG: expanded graphite; AF: aluminum foam; PW: paraffin wax

6.4. Thermal Management with Thermoelectric Module

Thermoelectric cooling systems are used in applications where temperature stabilization and cooling below ambient temperature is required. Fundamentals of thermoelectric cooling based on Peltier effect [116]. The Peltier effect is that when a direct current is supplied to a circuit consisting of two metal elements, the temperature increases with respect to the direction of the current, or vice versa. Figure 9 shows thermoelectric element which is integrated into the cooling system with forced convection. It can be understood that although the ambient temperature is high, the battery module can be cooled [94].

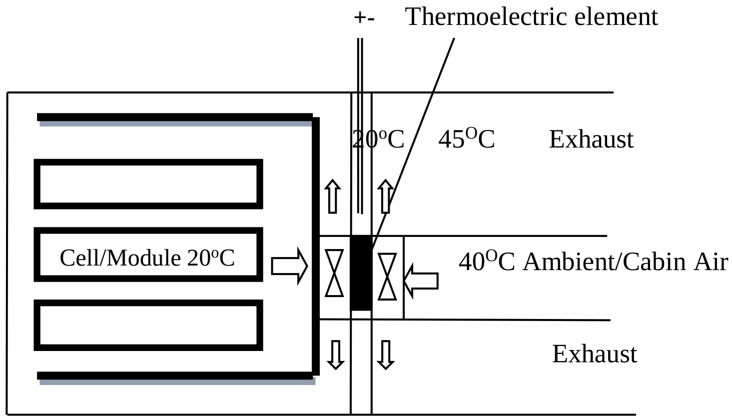

Figure 9. Thermoelectric cooling/heating system

6.5. Thermal Management with Heat Pipe

Another method used for thermal management systems is heat pipe. The heat pipe structure is given in Figure 10. The heat pipe is a cooling device which is used especially in electronic cooling systems [117]. The heat pipe is a system that operates with a phase change of the fluid inside, which is completely airtight, consisting of vacuum condenser and evaporator parts [118]. In the evaporator part, as a result of heating of the fluid, the phase change takes place and this change forms the pressure gradient. With the pressure gradient effect, the steam moves toward the condenser section. As the liquid at the end of the evaporator part turns into steam, vapor pressure increases at this point. Consequently, liquid-vapor interface is drawn into the evaporator in the wick. As a result of the withdrawal, in the condenser part, capillary pressure draws into the liquid inside the wick and flows to the evaporator part.

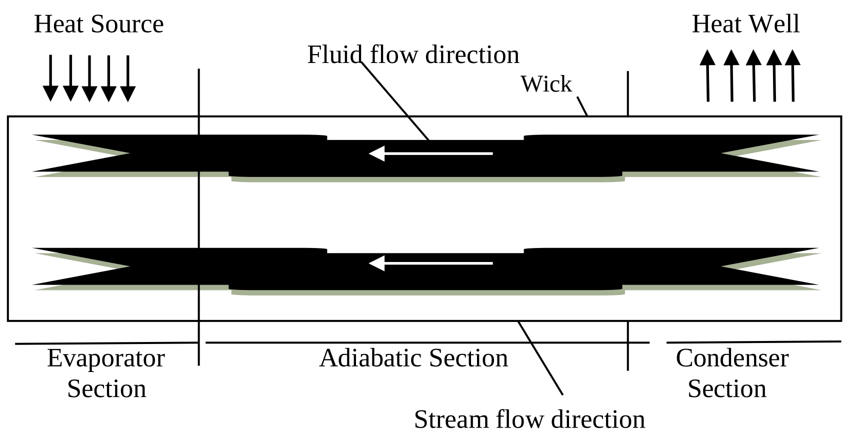

Figure 10. In some applications of the heat pipe, in the condenser part, heat removal can make more efficient with the addition of a fin [119]

7. Battery Heating

In general terms, battery thermal management is focused on cooling. Cooling has been kept in the front in order to decrease the increasing temperature that comes from the motors of the automobile and with the environmental conditions. Electric vehicles do not have any additional equipment to help heating the battery package. Therefore, the warming can be done by using the air coming from the motor. In addition, hot air which is in the cabin can be used to raise the temperature of the battery. Preheating is provided from the resistances, which are in the battery pack, because warming up the engine or the cabinet takes time in the first run at low temperatures[33]. As a result, the operation of the cells that the resistances support will lead to a significant temperature rise and cause the performance of the cells to rise again [120,121].

Today, under military conditions, li-ion batteries have to work under temperatures of -40 ° C. Especially, in temperatures below -30°C, electrolytes must not freeze in severe weather conditions in order to allow the operation of li-ion batteries. Thus, in order to increase the fluidity of the frozen electrodes, ethyl methyl carbonate is used [122–124].

8. The Effect of Battery Packaging on Heat Administration

The choice of battery thermal management depends on where the battery pack is installed and the environment conditions in which it is installed. In the design of the battery module, materials which are used in the modular, directly influences the selection and design of the thermal management system. It has been demonstrated that each of the modules, which makes up the battery package, must have stable temperature and temperature changes as though they were in the same cells in terms of temperature [90]. The cell, module and battery pack system are shown in Figure 11 [125]. The appropriate thermal design of a module has been shown to have a positive effect on overall package thermal management. The heat transfer rate among the modules walls depends on the conductance of the cell housing material or the heat transfer coefficient of the fluid which will be used [23].

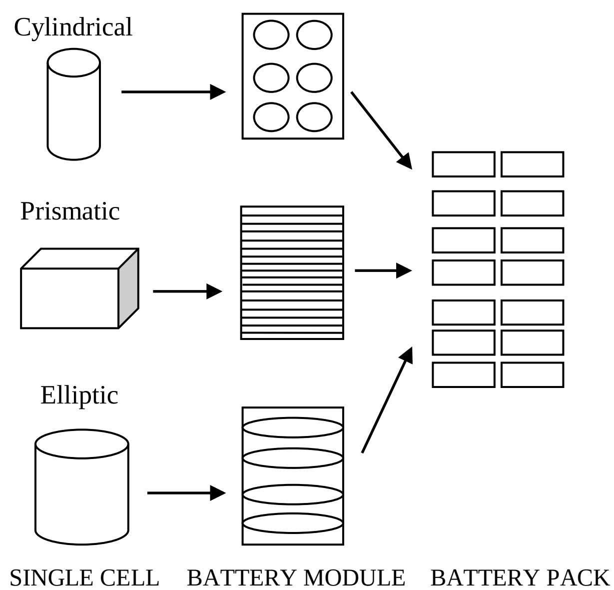

Figure 11. Schematics of the battery pack design with different cell configurations

Lou designed a 5-mesh package structure to increase heat transfer in Ni-MH batteries. In his design of packages in Lou's experimental studies, the temperature drop was the way you wanted it to be. However, the temperature difference between the batteries was still higher than 5^0C [126] (Figure 12).

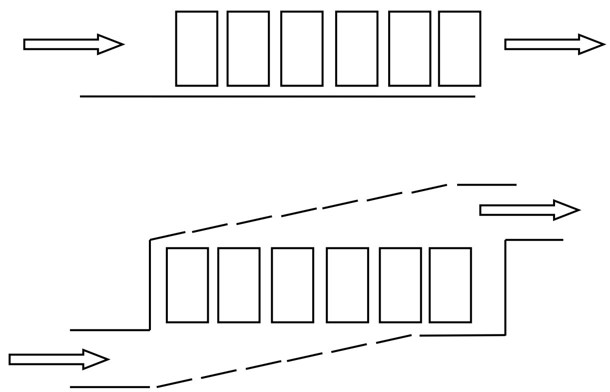

Figure 12. Air flow over the battery

9. Conclusions

It is understood that compared to other battery types such as Lead acid and Ni-MH, Li-ion batteries are better in terms of life, weight, volume and high energy storage capacity and are preferred by the sector due to these properties. When the research is considered, it seems that the optimum operating temperature for the batteries is between 25ºC - 45ºC. Again, according to the data obtained from the studies, it is recommended that the temperature difference between the cells is 5ºC maximum. High temperatures have been shown to deteriorate performance and efficiency of Ni-MH, VRLA and Li-Ion cell-based batteries, and have a negative effect on battery performance at low temperatures [68]. It has been stated that known thermal management systems should become more complicated if the temperature is in the range of 45ºC - 50ºC or below -10ºC [23]. It has been determined that the temperature variation between the modules is outside the permissible values, which can lead to different charging / discharging behavior and reduce the capacity of the battery package. This has led to a decrease in battery performance and the formation of unbalanced modules [90,127]. The main task of the battery thermal management system is to keep the battery at the desired temperature range and to minimize temperature changes [128,129].

It has been determined that in battery thermal management using air providing cooling / heating at medium levels is a simpler and less costly approach. However, it has been shown in researches that air-cooling / heating is not as effective as liquid-making in terms of heat transfer [130]. If passive heating / cooling performance with air is not what is desired it may be appropriate to support the system with a system such as thermoelectric or heat pipe. Thermoelectric modules are not recommended to be used alone in applications because they perform poorly when used alone [131,61]. Although liquid cooling is the most effective method for achieving efficient heat transfer between cells, it is disadvantageous in terms of the possibility of leaking, additional components that are needed and cost. It has been shown that in liquid cooling, indirect cooling is easier than direct cooling to manage in terms of direct cooling control [22,132]. In the study by Khateeb et al. [101], the result of the researches the thermal management, PCMs that are formed by incorporating metallic matrices into paraffinic composite materials instead of a single PCM, are more effective with phase change material [101]. In practice, thermal management systems with PCM are generally regarded as being operated in an integrated manner with systems using passive or active air. At low temperatures, there are two methods to improve the performance of the li-ion battery. One of these methods is increasing temperature to increase the energy of the molecules and another method is by using different electrode structures to increase the intermediate surface area [69,80,133–140]. In the battery package design, it is determined that there should not be any problems that obstruct the thermal management system, it should be designed to allow air flow or fluid flow, and that the module designs should use materials with high transmission coefficient [90,141].

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