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A Review on Cooling Methods of Lithium-Ion Battery Pack for Electric Vehicles Applications

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ABSTRACT

The thermal concerns, such as capacity loss, uneven temperature distribution and thermal runaway of the battery packs made of lithium-ion batteries (LIB) used in electric vehicles (EV), limits its applicability, especially in situations of high-power demand. This article analyses the causes of heat generation in lithium-ion battery packs, focusing on their dominance over total heat generation. It discusses the thermal issues arising from heat generation, their root causes, and influencing parameters. Further, it examines the effect of cooling systems on peak battery temperature and temperature uniformity, as well as their design, operating, and performance parameters. The review suggests that, when designing a cooling system, entropic heating should be considered alongside Joule heating during low discharge rates and high temperatures, which are the conditions that prevail when an EV cruises on highways in hot weather. Capacity fade of battery is caused by temperature-dependent factors such as the growth of the SEI layer, rise in separator resistance, and active material loss. Hence an effective battery cooling system should maintain a temperature range of 15°C to 35°C and 'ΔT_{max}' below 6°C. Out of the reviewed cooling systems, air cooling is found to be simple and cost effective, but inefficient for large battery packs. PCM based cooling technique offers greater temperature uniformity but is sensitive to melting point. Liquid cooling is most efficient but adds cost and complexity. Evaporative cooling can serve as a middle ground between air and liquid cooling with further research to put it into practice. The future research in battery thermal management may focus lowering the energy consumption of the cooling systems by taking into account, the precise cooling needs as per the modes of battery operation.

1. Introduction

Internal Combustion engines have been the source of power supply for self-propelling vehicles since last century [1]. These engines mainly utilize hydrocarbon fuels which have limited resource. There have been concerns regarding the over-reliance and continuously increasing costs of petroleum oil as well as harmful emissions and global warming over past several decades. This has

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prompted the researchers to conduct more in-depth investigations into the vehicles powered by renewable and environmentally friendly energy sources.

In the last decade, the emergence of high capacity anode and cathode materials for batteries has disrupted the conventional I. C. engine technology [2]. A comparison of different battery technologies like lead-acid (Pb-acid), Nickel-Cadmium (Ni-Cd), Nickel-Metal-Hydride (NiMH) and Lithium-Ion (Li-ion) reveals that the widespread use of LIBs in EVs is primarily due to their extremely high charge storage capacities per unit weight, which determines the range of the EV, and the high power density, which determines the acceleration performance [3,4]. Lithium-ion batteries also have a long cycling life, a wider range of working temperature, a consistent charge-discharge cycle, high efficiency, and a low self-discharge rate, which makes them ideal for EV applications. As new battery materials are developed, the above-mentioned properties continue to improve [5].

However, various thermal concerns arise on account of heat generated inside the battery. It has been observed that when temperature rises, battery performance diminishes rapidly [5-7]. At extreme temperatures, a lithium ion battery may experience Thermal Runaway (TR), a chain of exothermic events that raises the temperature even more until irreparable damages occur [6,7]. To address these challenges, a good Battery Thermal Management System (BTMS) must be developed in order to keep the battery temperature within the optimal range [7,8]. A well-built BTMS might efficiently manage battery temperature while ensuring safety and performance enhancement.

Pertaining to the thermal control of EV batteries, three cooling technologies have received considerable attention : (1) air-cooling, (2) liquid cooling, and (3) phase-change material (PCM) based cooling [9]. Furthermore, some other cooling methods like heat pipe cooling, submerged cooling, evaporative cooling, air jet impingement cooling are also being explored by the researchers.

This review paper addresses the research done in recent years in order to comprehend the mechanism and possible causes of heat generation, different thermal problems, and their root causes. It focuses on the efforts made by various researchers in developing temperature management techniques like air cooling, liquid cooling, phase change material, heat pipe, non-conventional cooling such evaporative cooling as well as their performance-influencing factors. This review article will assist the readers for not only in focusing on those areas where heat generation has a high impact but also in improving the performance of the BTMS by using the various approaches addressed in this paper.

2. Heat Generation

During the process of charging or discharging the energy stored inside LIB is utilized in two ways: major portion of the stored energy is converted into electric work and remaining portion is dissipated as heat due to which the battery temperature rises. As per the classic research article of Bernardi *et al.,* [10] temperature change of battery cell is caused by the electrochemical reactions, phase changes, mixing effects and joule effect. According to Yang *et al.,* [11], in case of electrochemical reactions with good transport properties, mixing-generated heat can usually be disregarded. In addition, the phase change terms are null if all the chemical species participating in electrochemical reactions within the cell are in the same phase. Therefore, the shortened version of the equation proposed by Bernardi *et al.,* [10] is as follows

$$\dot{Q} = I\ (V_{oc} - V_t) - IT\ \left(\frac{V_{oc}}{dT}\right) \tag{1}$$

where, $\dot{Q}$ is total rate of internal energy generation inside battery, V_{oc} is open circuit voltage, V_t is terminal voltage, T is battery temperature, and I is current flowing across battery. $(V_{oc} - V_t)$ is the cell overpotential which is an indication of the irreversibilities such as Ohmic losses, charge-transfer overpotentials and mass transfer limitations. The overpotential term can be modified as: $I(V_{oc} - V_t) = \mathrm{I} \times R_{int} = I^2 R_{int}$ and the heat generation equation can be expressed as

$$\dot{Q} = I^2 R_{int} - IT\left(\frac{V_{oc}}{dT}\right) \tag{2}$$

where, R_{int} is the internal resistance of the battery.

Eq. (2) suggest that heat generation may occur during both charging as well as discharging, however as per the research of Eddahech *et al.,* [12], it is more pronounced during the discharge phase as shown in Figure 1.

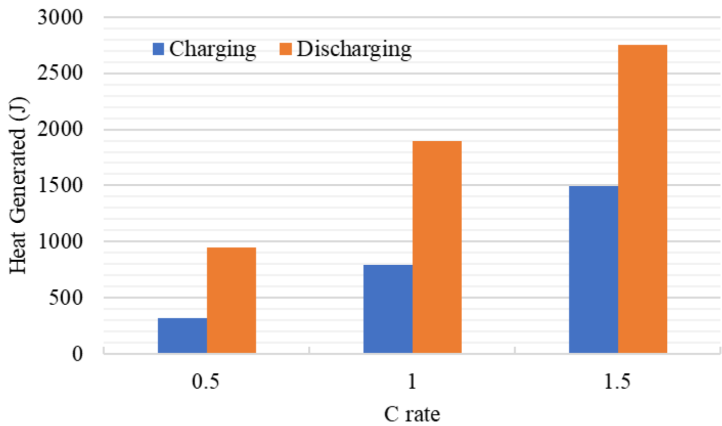


Fig. 1. Battery heat loss during charge and discharge at several C-rates [12]

2.1 Reversible and Irreversible Heat Components

The total heat generation is categorized into irreversible and reversible heat as follows:

$$\dot{Q_{irr}} = I^2 R_{int} \tag{3}$$

$$\dot{Q_{rev}} = -IT\left(\frac{V_{oc}}{dT}\right) \tag{4}$$

The *irreversible heat* which is also called as Joule heat is due to internal resistance of the battery to current flow. The 'R_{int}' of battery is a combined effect of resistance due to solid electrolyte interface (SEI) layer, transfer of Li-ions at electrode interface, diffusion of ions at electrodes and Ohmic resistance [13]. R_{int} is also a function of temperature, C-rate and depth of discharge (DOD) and age of the battery. It is found to vary inversely with temperature and directly with C-rate [14]. The variation of R_{int} with DOD (*d*) for typical pouch cell at 1C, 25 ° C is given by the following equation [15].

$$R_{int} = 3.96E - 6\, d^4 - 0.000651 d^3 + 0.0404 d^2 - 1.035 d + 17.143 \tag{5}$$

It is exothermic type of heat during both charging as well as discharging since it is proportional to the square of the current.

The *reversible heat* $(\dot{Q_{rev}})$ is also known as Entropic Heat. It is the effect of the intercalation and de-intercalation of Li-ions at the electrodes during charge and discharge [16]. It is affected by C-rate, temperature and entropy coefficient $\left(\frac{V_{oc}}{dT}\right)$ which is also known as temperature coefficient of OCV. The entropy coefficient $\left(\frac{V_{oc}}{dT}\right)$ varies with V_{oc} which is a function of depth of discharge (DOD). Table 1 shows that the entropic coefficient is positive across the complete DOD range, except at DOD=0.8 [17].

Table 1
Entropic coefficient at different DOD levels [17]

DOD	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
$\frac{V_{oc}}{dT}$ (mV/K)	0.076	0.079	0.056	0.141	0.169	0.137	0.049	-0.101	0.060

Many researchers have contributed to the comprehension of the relative dominance of the reversible and irreversible components on the total heat generation and their effects. Singh *et al.,* [18] discovered that at a low rate of 1C, $\dot{Q_{rev}}$ contributes the most to total heat production in a battery cell. Lu *et al.,* [17] noted that, during charging, the $\dot{Q_{rev}}$ remains negative, indicating an endothermic reaction and positive during discharging, indicating an exothermic reaction. However $\dot{Q_{irr}}$ was always positive in both the operations [17]. Further, the magnitude of $\dot{Q_{rev}}$ was found to be constant for all C rates, whereas that of the $\dot{Q_{irr}}$ increases with C rate during charging and discharging. Furthermore, $\dot{Q_{irr}}$ was higher during discharging than charging for the same C-rates as shown in Figure 2 [19]. This is because the battery's internal resistance is greater during discharging than charging [20]. These studies confirm that reversible heat dominates at low discharge rates, while irreversible heat dominates at medium and high discharge rates.

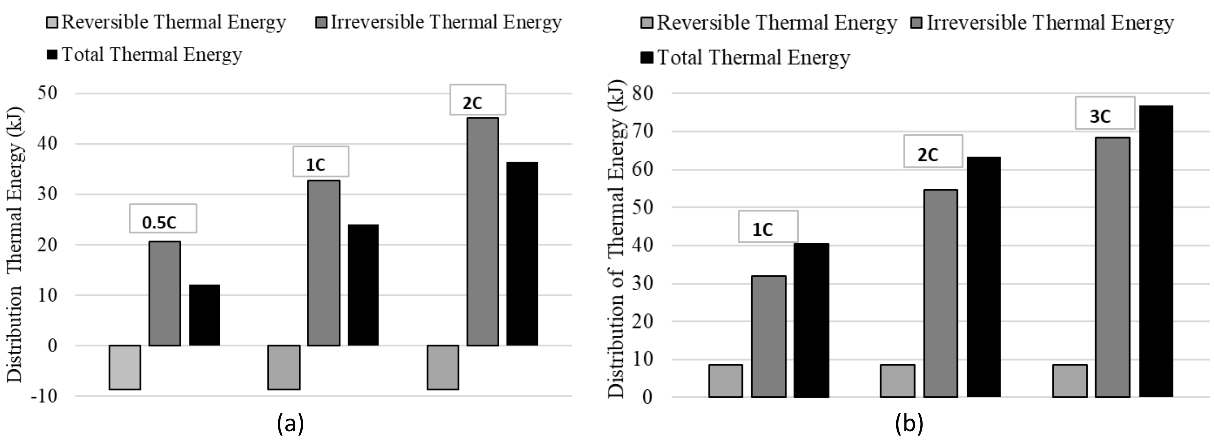


Fig. 2. Distribution of thermal energy including irreversible heat $(\dot{Q_{irr}})$, reversible heat $(\dot{Q_{rev}})$, and total heat $(\dot{Q}$) in the cell under different (a) charge rates and (b) discharge rates [19]

According to the research findings discussed in this section, irreversible heat could be considered as the only heat source term to trim off the heat generation thermal model of the LIB when discharged at rates greater than 1 C in the optimal temperature band of 20°C to 40°C. However, the reversible component of heat generation cannot be ignored in EV applications where the battery undergoes discharging at low rates, particularly during cruising operations in hot summer conditions.

3. Thermal Issues

This section delves into the thermal issues due to high temperature, their root causes and influencing parameters like temperature and C-rate.

3.1 Capacity Deterioration

The storage-capacity of Lithium-ion battery degrades over time as a consequence of continuous cycling. This is called as Capacity fade. The causes of capacity fading are reviewed below.

Cheng *et al.,* [21] found that the capacity of NMC-18650 battery decreased by about 12 times from 100 to 500 cycles. The capacity drop can be mainly related to increase in the resistance to transfer of charge at anode due to Solid-Electrolyte-Interphase layer (SEI-layer) and Lithium fluoride (LiF) production, increased mass transfer resistance of separator due to deposition of products of side reaction and loss of active material at anode to a lesser extent. Eddahech *et al.,* [12] experimentally tested the capacity of LIB at different C rates viz. 0.5C, 1C and 1.5C at 25^oC and found that it reduced from 12.55 Ah to 12.14 Ah to 11.95 Ah respectively. Ye *et al.,* [22], based on their simulation of $LiFePO_4$/graphite battery by 2-D electrochemical-thermal life cycle model found that in a single cycle, the battery capacity appears to increase slightly with temperature (4.6% rise), but it decreases significantly when batteries undergo additional rounds of high-temperature discharge (28% loss over 1707 cycles). The authors attribute the capacity fade to active lithium loss caused by the instability of the carbon negative electrode/electrolyte interface.

3.1.1 Effect of SEI-layer

SEI-layer which is the major cause of capacity fade is formed on the anode of lithium-ion batteries during the initial charging cycles [23]. According Heiskanen *et al.,* [24], SEI is formed due to decomposition of electrolyte which itself prohibits further decomposition and offers a prolonged calendar life. It enables LIB to be reversibly charged and discharged. The SEI thickens further with age, as shown in Figure 3 due to formation of chemical compounds like lithium ethylene decarbonate (LEDC) and LiF.

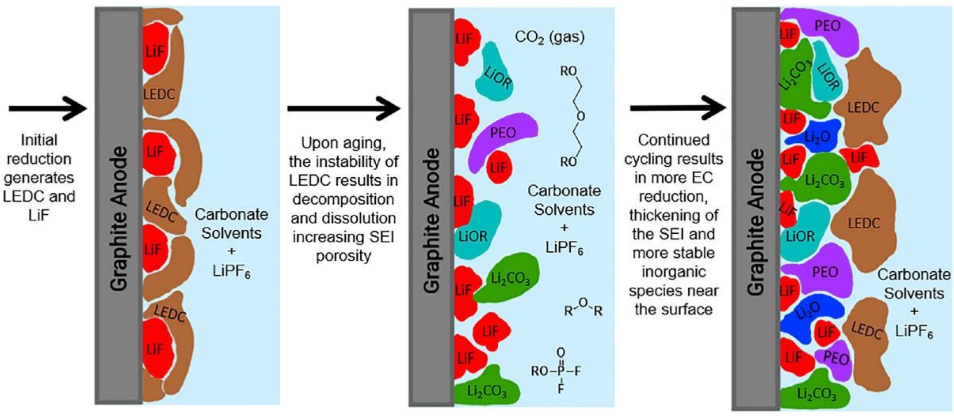


Fig. 3. Schematic diagram of growth of SEI on the Graphite Anode [24]

The SEI layer growth is observed to be caused by a complex chemical reaction between the electrolyte and the active lithium-ions that are passed through the electrolyte during charging and discharging. Because the rate of a chemical reaction is directly proportional to temperature, it stands to reason that if the battery is cycled at high temperatures, the SEI layer will grow faster, resulting in higher internal resistance, which will increase Joule heating loss. And, as the SEI layer grows, it consumes more and more Lithium ions, resulting in faster degradation of battery capacity.

3.1.2 Calendar aging

Understanding calendar ageing (aging without loading) of 'LIB' is useful in EV applications, in case the vehicle is to be parked in a garage or showroom for a long time. Maures *et al.,* [25] looked into to how temperature and time influenced degenerative effects such as loss of conductivity (CL), loss of active material (LAM), and loss of lithium inventory (LLM). For an 18650/NCA/graphite battery, each of these degradations was observed to increase with time (from -20^o to 55^o). This study suggests that CL, LAM, and LLM are the primary causes of LIB calendar ageing, which is directly related to ambient temperature. Motloch and co-workers indicated that in the temperature range of 30^{o}C to 40^{o}C for every one degree rise of temperature the calendar life of LIB decreases by around 60 days [26].

3.2 Thermal Runaway

LIBs are susceptible to 'Thermal Runaway' (TR) when exposed to elevated temperatures. This is a chain of heat-evolving reactions that causes further heating and potentially catastrophic outcomes [6,7]. The causes of 'TR' and the temperature limits are explored in the following discussion.

Because of the high energy storage, 'LIBs' are more vulnerable to thermal runaway in hot environments and at high state of charge (SOC) [27]. Thermal runaway has been revealed to be influenced by the 'SOC' that calculates how much charge is still remaining in a battery with a specific charge capacity. With increasing SOC, the temperature at which the 'TR' turns on, decreases and the maximum self-heating rate increases [28,29]. According to Feng *et al.,* [30], since the decomposition of the protective SEI layer begins above 50^{o}C the battery is more likely to enter thermal runaway above 50^{o}C. The attainment of temperature at which the thermal runaway turns on at the beginning of the second stage (85^{o}C to 105^{o}C in this case) may be viewed as an early warning of thermal runaway because it occurs well before the exponential rise in temperature. After reaching the onset temperature, the temperature rises exponentially, but before it, an abrupt voltage drop is observed [27]. Aged batteries undergo thermal runaway faster than new batteries, but they release less energy and achieve a lower maximum temperature (T_{max}) when compared to new batteries at 100% SOC. The explosion of aged battery is less hazardous than that of new battery as the amount of energy released and T_{max} attained is less [29]. However, thermal runaway hazards of aged batteries at different SOCs should be investigated before generalizing. As the discharge rate increases, the time it takes for thermal runaway to begin decreases [27].

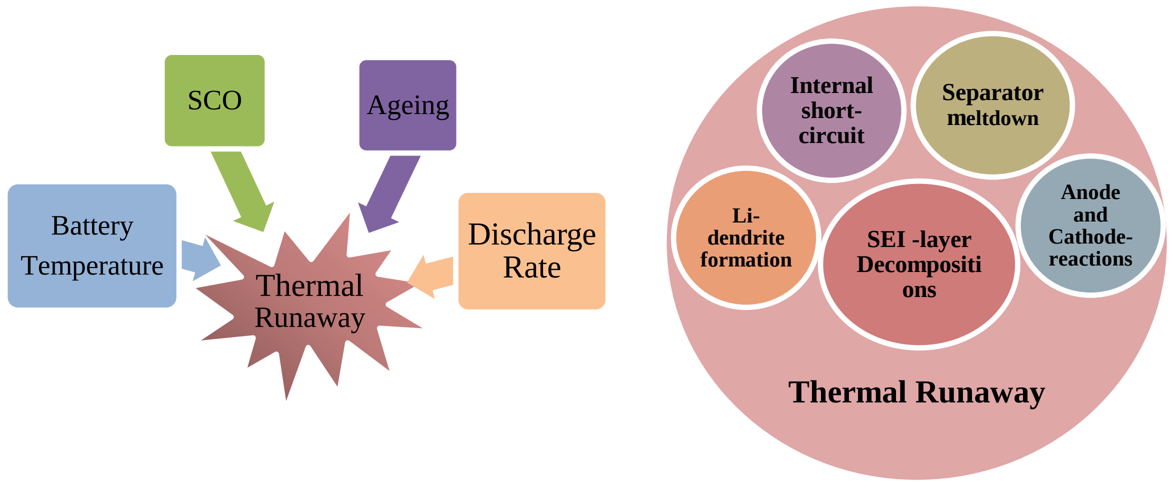
Table 2 shows the six distinct stages of thermal runaway that are identified by Feng *et al.,* [30]. The meltdown of separator (at around 137 ^{o}C) and the subsequent internal short circuit is one of the crucial stages, since at this point, violent exothermic reactions begin, resulting in thermal runaway and a sudden voltage drop to zero. Thermal runaway, however, can occur even when there is no internal short circuit but due to separator failure because of chemical crossover or crosstalk between the cathode and anode [31].

Table 2
Salient features and temperature ranges of the stages of thermal runaway during EV-ARC test on large format LIB [30]

Stage	Salient features	Temperature range
I	Capacity fade and de-intercalation of Li-ions from anode	37 °C to 94 °C
II	SEI decomposition, reaction of anode with the electrolyte releasing noticeable heat	94 °C to 137 °C
III	Separator starts to melt, temperature rise slows down as a result of latent heat absorption by separator	around 137 °C
IV	Internal micro-short circuit, anode reaction consumes active material.	137 °C to 259 °C
V	Exponential rise in temperature, separator disintegration, severe internal short circuit decomposition of cathode, electrolyte and binder, sudden voltage drop	259 °C to 750 °C
VI	Continuance of remaining reactions	750 °C to 853.5 °C

Thermal runaway is a high temperature phenomenon, but it has low temperature connection as well. A Lithium ion cell which is cycled at low temperature is more prone to thermal runaway as compared to fresh cell because of deposition of Li-dendrites on anode which decomposes the electrolyte rapidly reducing the temperature at which 'TR' sets on [32].

Based on the findings discussed in this sub-section, it can be inferred that external parameters such as SOC, temperature, ageing, and discharge rate all have an impact on thermal runaway (Figure 4). But temperature and discharge rate are the most influential parameters since they influence the rate of chemical reaction. Above 50°C mark the risk of TR is high due to the possible onset of decomposition of the protective SEI layer. Among the internal causes of thermal runaway are the disintegration of the SEI-layer, deposition of Li- dendrites on the anode, and internal short circuit.



(a) (b)

Fig. 4. (a) External influencing parameters and (b) Internal causes of thermal runaway

3.3 Temperature Variation

Another thermal issues which pose challenge in the thermal management of battery pack the is non uniform temperature distribution inside a single cell and inside a battery pack. As most of the electrochemical reactions happen at the electrodes, the pace of heat production is not identical at different locations in a Li-ion cell. The positive electrode reportedly releases nearly four times as much heat as the entire battery [33]. A battery pack is made up of multiple cells arranged in series and parallel combination as per the voltage and current requirements of the application [23]. Maldistribution of temperature inside a battery pack occurs due to mutual heating effect and uneven cooling of the cell. Centrally located cells are heated more as compared to the cells located near the sides of a battery pack. If a uniform cell temperature is not maintained, different cells age differently, putting pressure on the cell balancing system required to keep the cells in the same SOC. This would reduce the usable capacity of the battery [34]. The maximum temperature difference between the hottest and the coldest cell (ΔT_{max}) should be less than 6°C [35,36].

Maintaining temperature uniformity inside a battery pack can be considered as another crucial factor for designing a good BTMS. Knowledge of temperature variation of battery during both operations is essential for effective battery heat management. Shi *et al.,* [37] in their experimental work state that there is a difference in temperature rise during charging and discharging. It has been found that discharging causes more temperature rise than charging does. Huang *et al.,* [38] confirmed the nonlinear nature of battery temperature variation w.r.t time, which can be attributed to the changes in internal resistance, polarization heat, entropy coefficient, and variation of open circuit voltage (OCV) with respect to SOC, all of which change continuously during charging and discharging.

3.4 Temperature Range

Many researchers have been taking efforts to figure out the range of temperature for safe operation and for optimum performance. Liu *et al.,* [39] reported in their review article that the tolerable temperature of 'LIB' is - 20°C to 60°C, however for optimum performance, these batteries should be operated in the narrow range of 15°C to 35°C. Pesaran [40] established a working temperature baseline for various battery types, recommending an optimal range between 25°C to 40°C, with a maximum 5°C variation among modules. He demonstrated the impact of temperature on LIBs' life, safety, and functionality, proposing a 15-35°C range. R. Korthauer claims that below 20 °C, battery performance (available power) falls significantly due to the increase in internal resistance. Moreover, battery aging accelerates due to 'lithium plating' below 0 °C. On the other hand, for every 10°C above 40°C, the battery service life would be reduced by 50%. Hence for acceptable service life battery the BTMS should be configured between 20°C to 40°C, keeping it closer to the lower temperature limit [34].

A recent experimental study on high power Prismatic LFP-polymer cell under various ambient temperatures shows that based on its efficiency and charge capacity, the optimal operating temperature range for a LIB is 30°C to 40°C. At approximately 31°C and 1C-rate, both the Coulombic efficiency and the capacity are at their maximum as shown in the Figure 5 [41].

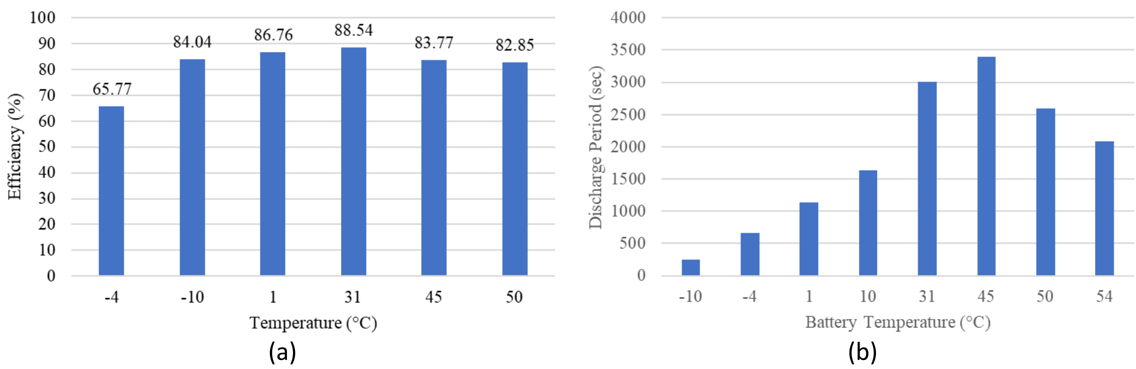


Fig. 5. (a) Variation of battery efficiency with temperature at 1 C-rate (b) Discharge period during discharge at 1 C-rate at different temperatures [41]

Table 3 summarises the findings of the researchers about the optimal and operating range of battery temperature.

Table 3
Operating and optimum Temperature Range of lithium-ion battery

Name of Author	Operating Temperature Range	Optimum Temperature Range	Remark
Liu *et al.,* [39]	-20°C to 60°C	15°C to 35°C	--
Korthauer [34]	-20°C to 60°C	20°C to 40°C	Acceptable aging
Pesaran [40]	---	25 °C to 40 °C	maximum of 5°C variation between modules
Pesaran [42] and Pesaran *et al.*, [43]	---	15°C to 35°C	temperature effects on life, safety and performance
Ladrech [44]	0°C to 60°C	20°C to 30°C	--
Chatterjee *et al.,* [41]	---	30°C to 40°C	Efficiency and energy storage ability is maximum
Lu *et al.,* [17]	---	20°C to 40°C	Maximum charge and discharge capacity

From the above discussion, it can be suggested that the for optimum performance of the battery, it should be operated in the narrow range of temperature of 15°C to 40°C with ΔT_{max} below 6°C mark.

4. Cooling Methods for Thermal Management of EV Battery

The researchers have investigated various cooling techniques in order to keep the temperature of the LIB within the optimal range. Active cooling, passive cooling, and hybrid cooling are the three types of cooling technologies based on energy usage, as indicated in Figure 6. Active cooling requires a significant amount of energy to power a fan, pump, or compressor in order to circulate or pressurize the coolant fluid. Passive cooling requires little or no energy to operate. Hybrid cooling which combines active and passive cooling methods, such as PCM+air, PCM+liquid, or PCM+heat pipe has recently attracted the attention of researchers as well.

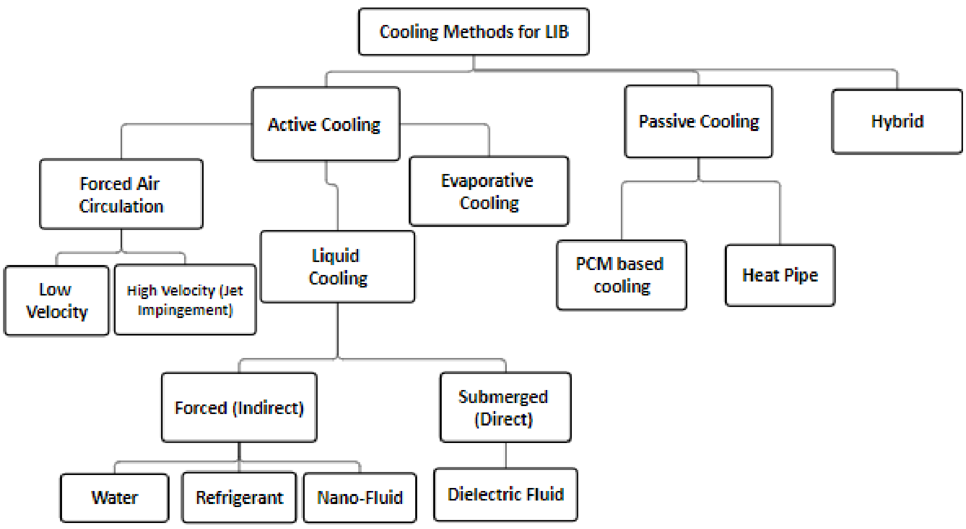


Fig. 6. Classification of cooling techniques used for LIB

4.1 Air Cooling

This method has been implemented by many electric vehicle manufacturers for their EV models like Toyota Prius, Nissan Leaf, Honda Insight, Roewe Marvel X etc [45]. Air cooling system adopted in EVs can be passive or active [21]. In an active air-cooling system pre-conditioned air is taken from a heater or air conditioner. In a passive system air is directly taken from the atmosphere or the cabin. Passive systems can typically absorb or dissipate hundreds of watts thermal energy, whereas the capacity of active systems is restricted to around 1 kW [46].

In the case when forced air cooling is used, the location of fan plays a crucial role because it decides whether all the cells in the pack will get sufficient amount of air to maintain the required temperature. Regardless of the layout of the battery pack, the most efficient cooling is achieved when the fan is positioned on the top of the battery module with temperature near the outlet and near middle cells as compared to near the fan [47]. According to a numerical simulation, cooling effectiveness is significantly boosted when the airflow inlet and outlet are both placed on the roof of the battery [48]. Chen *et al.,* [49] studied forced air circulation based BTMS with various locations of the inlet and the outlet regions by using the numerical method and validated its effectiveness experimentally. Results indicate that the symmetrical BTMS with inlet and outlet situated at the centre of the plenums attains more efficient than other locations. According to Zhang *et al.,* [50], the single inlet at top and four outlets (1I 4O) at the bottommost of side walls of the battery (Figure 7) is the most effective among the all other multiple inlet and outlet arrangement (1I 1O, 1I 2O, 1I 4O), (2I IO,2I 2O, 2I 4O),(4I 1O, 4I 2O,4I 4O). It could limit the T_{max} to 36.6 °C and $(\Delta T)_{max}$ to 3.3 °C. The reason for this is air flow axis is parallel to the axis of cylindrical cells.

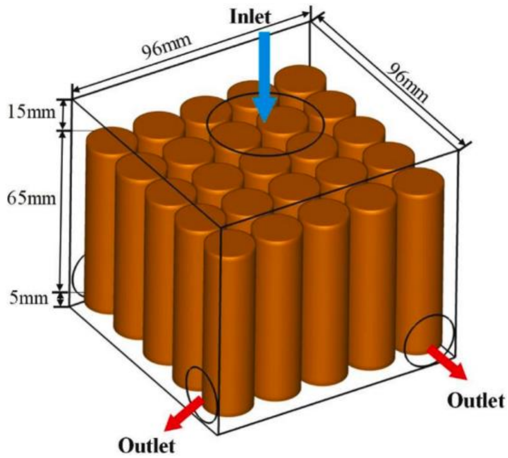


Fig. 7. BTMS with 1 inlet and 4 outlets [50]

The physical arrangement of cells (Figure 8) also influences the effectiveness of the thermal management by air cooling method.

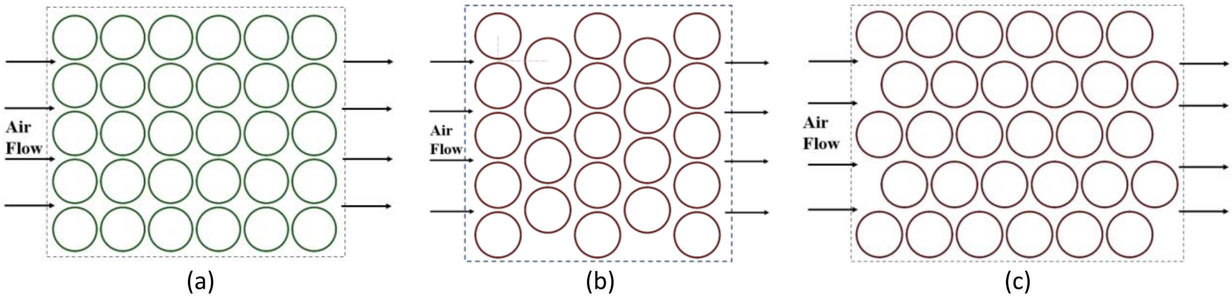


Fig. 8. Types of cell arrangements inside battery pack (a) Inline (b) Staggered (c) Cross

Among the aligned, staggered, and cross-type cell configurations, aligned arrangement has the highest cooling efficiency and minimal power consumption [51]. The staggered cell arrangement resulted in more uniform temperature distribution for all C-rates compared to in-line arrangement while the later was little bit better as far as maximum temperature rise is considered [38]. But, when the number of cells is increased beyond a certain value, the cell arrangement appears to have little influence on temperature uniformity in the module. This might be because of the heat that is constantly building up and the relatively lower heat dissipation from the cells downstream of the airflow [18]. The rectangular configuration is superior to the square one due to its lower peak temperature pattern. However, the temperature variation of square-shaped battery packs is superior to that of rectangular battery packs [52].

The design of cooling channel is the next consideration for optimizing the air cooling system once the battery pack configuration is chosen. For staggered arrangement of cylindrical cells, it is proposed that larger cooling channel size improves the cooling efficiency and lowers the peak temperature at the cost of size of battery pack. However increasing channel size beyond a certain limit doesn't add much benefit [48]. Widyantara *et al.,* [53], modified the battery through altering the number of cooling fans. According to analysis, the better way to dissipate the heat between lithium batteries was to lower the airflow temperature and raise the number of cooling fans. By varying the positions of the intel and outlet ports. Chen *et al.,* [54] developed multiple combinations of symmetric and asymmetric cooling arrangements. This comparison revealed that the asymmetrical system reduced the T_{max} values by at least 43% and energy consumption by at least 33% under different inlet airflow rates. Zhang *et al.,* [55] studied the effect of spoilers in a battery pack's cooling system by analysing their cooling performance. They found maximum drop in T_{max} at 80^{o} angle, and the best performance with progressively increasing spoiler heights from inlet to outlet. Furthermore, the improvement of effective heat transfer areas between air-coolant and battery surfaces can reduce the maximum temperature and improve the temperature gradient in a densely packed battery box as well [45]. Chen *et al.,* [56] presented a comparison of four cooling structures: air cooling, direct liquid cooling, indirect liquid cooling, and fin cooling based on numerical analysis of prismatic cell using ANSYS/Fluent.

After reviewing the articles on air cooling method, it can be stated that the air cooling, despite being a cost-effective and less complex technique, is less efficient at high discharge rates due to the low convective heat transfer coefficient of air. However, optimizing the parameters shown in Figure 9 can enhance the design and performance of air cooling.

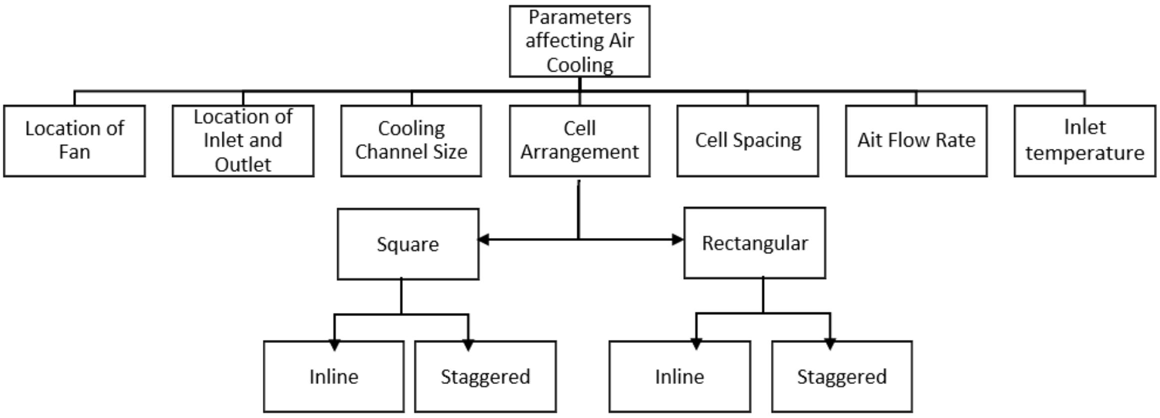


Fig. 9. Parameters related to the design/performance of air-cooling system for EV battery

Following equations are used for the mathematical modelling of air/liquid cooled systems.

The heat absorbed by the air-coolant from the battery surface is given by

$$\dot{Q} = hA(T_s - T_\infty) \tag{6}$$

where, $\dot{Q}$ is rate of heat rejected to the air which can be calculated by Eq. (2), T_s and T_∞ are the surface temperature of battery and air temperature respectively. The temporal variation of 'T_s' can be calculated by solving the conservation of mass, momentum and energy equations for 2-dimensional flow as [57]

Conservation of mass

$$\frac{\partial(\rho)}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0 \tag{7}$$

Conservation of momentum

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) \tag{8}$$

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho uv)}{\partial x} = -\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right) \tag{9}$$

Conservation of energy

$$\frac{\partial(\rho C_p T_\infty)}{\partial t} + \frac{\partial(\rho u C_p T_\infty)}{\partial x} + \frac{\partial(\rho v C_p T_\infty)}{\partial y} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) \tag{10}$$

4.2 Liquid Cooling

In the case of high-power battery packs, liquid cooling is chosen due to the better coefficients of convective heat transfer of liquids in comparison to air. In this system, liquid coolant is passed through cooling channels that are located near the battery cells.

Flow rate of the coolant seems to be an influencing parameter in this method. As per the study on a mini-channel based liquid cooling system the T_{max} and ΔT_{max} are seen to be decreasing with increase in the quantity of mini channels and flow rate for a given arrangement of flow, the later being more influencing a factor [58]. Wang *et al.,* [59] found that after a limiting value of flow rate, the highest temperature and temperature consistency could not be substantially enhanced , while power consumption increased. According to a study on the dynamic behaviour of a 48-cell liquid-cooled battery module increasing the coolant mass flow rate reduces the surface temperature of battery, but only until a certain upper limit value is reached, after which the effect of flow rate diminishes with increase in C-rate as seen in Figure 10 [60].

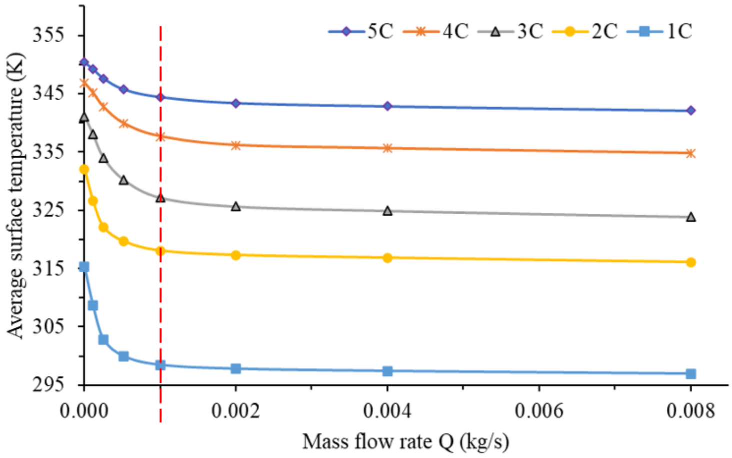


Fig. 10. Effect of mass flow rate on average surface temperature of batterie at different C-rates [60]

In high power 'EVs' refrigerant of the vehicle's 'heating ventilation and air conditioning system' (HVAC) is used as a cooling fluid (Figure 11). In direct refrigerant cooling the refrigerant is circulated through the cooling plate channel situated around the batteries. In indirect refrigerant cooling the refrigerant is used to cool down another coolant (generally water + ethylene glycol) which in turn is circulated though the cold plate to absorbs heat from battery pack. With the use of fins in the refrigerant heat exchanger, the temperature of the battery pack can be controlled under 35 °C in extreme surrounding temperature of 40°C and the 'ΔT_{max}' can be maintained well below 4 °C for typical road drive cycles [61]. Shen and Gao's [62] analysis of a novel refrigerant based BTMS for EVs in high-temperature and dynamic situations demonstrated that the mean battery temperature and ΔT_{max} were effectively managed, but intensified driving conditions and surrounding temperature negatively impacted the COP of the system. The refrigerant-based heat management system is found to be effective in preventing the spread of thermal runaway from one cell to the next, although it couldn't prevent the thermal abuse of single cell [63].

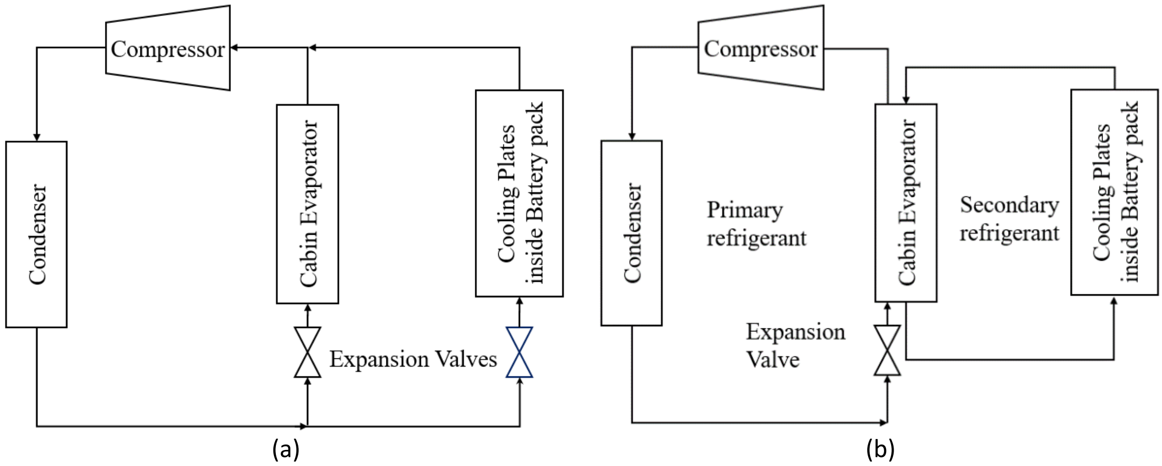


Fig. 11. Refrigerant-based cooling arrangements (a) Direct (b) Indirect

In a comparative numerical investigation of a battery module, it is discovered that liquid cooling method is more effective than the air-cooling method for the same of power usage (Figure 12). But the effect of mass flow rate is much more significant in air cooling than in liquid cooling as the maximum temperature drop in the former was about 3.7 °C greater than the latter [64].

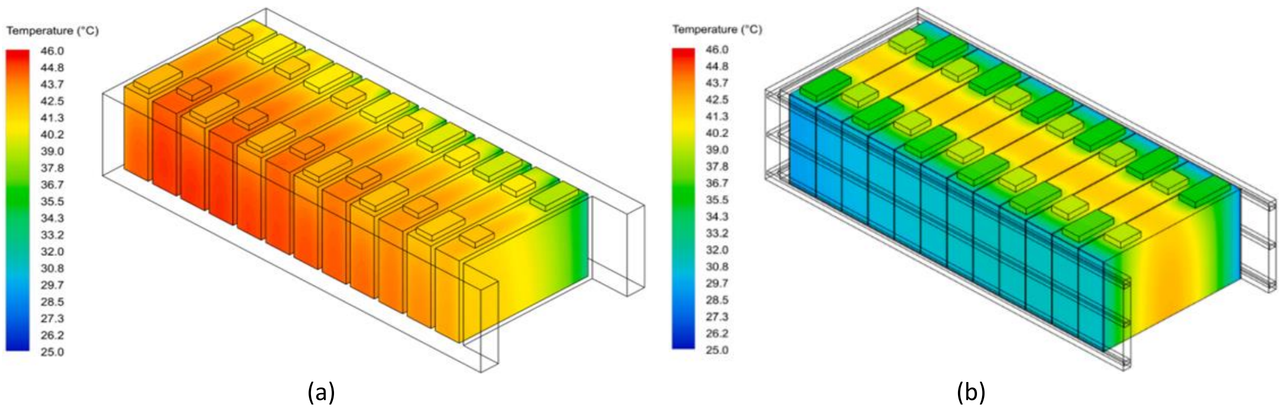


Fig. 12. Surface Temperature distribution on the module with (a) air cooling system (b) liquid cooling system [64]

The structure and design of the cooling channel were noticed to have an impact on the performance of liquid-based cooling. Ding *et al.,* [65], perceived that temperature uniformity was improved by increasing the number of channels and aspect ratio, though the latter had a negative impact if increased above a certain limit. Studies have shown that interspersed cooling plate design is most effective in improving cooling performance and temperature distribution in pouch cell battery-systems [60]. Cen *et al.,* [61] found that forming multiple flow channels with a canopy structure can achieve the same thermal performance as a plain volume cooling system with lower coolant flow rate. Shen and Gao [62] found that the positions of the outlet and inlet, along with the directions of flow, significantly impact temperature distribution. According to Ping *et al.,* [63] a semi-helical duct structure for cooling battery packs made of 18650 cells with water as coolant, was more efficient than jacket cooling (49% drop in T_{max} and 17 % drop in ΔT_{max}). Akbarzadeh *et al.,* [64] introduced three different types of conductive structures between cells and cooling channels to improve contact area and heat dissipation rate (14% drop in ΔT_{max}). A combination of thermoelectric (TE) cooling and indirect liquid cooling in which forced air circulation was utilized cool the TE operation was tested by Lyu *et al.,* [66] on a battery simulator. The experimental results showed a drop of 43°C in battery surface temperature.

From the review presented in this section we may infer that liquid cooling system is very effective in maintaining the 'T_{max}' and 'ΔT_{max}' within the limit. But the drawback of liquid cooling is high initial cost and added complexity due to more number of components. However the cost can be controlled by optimising the parameters such as type of coolant, flow rate, inlet temperature , number of flow channels, aspect ratio, flow arrangements as depicted in Figure 13.

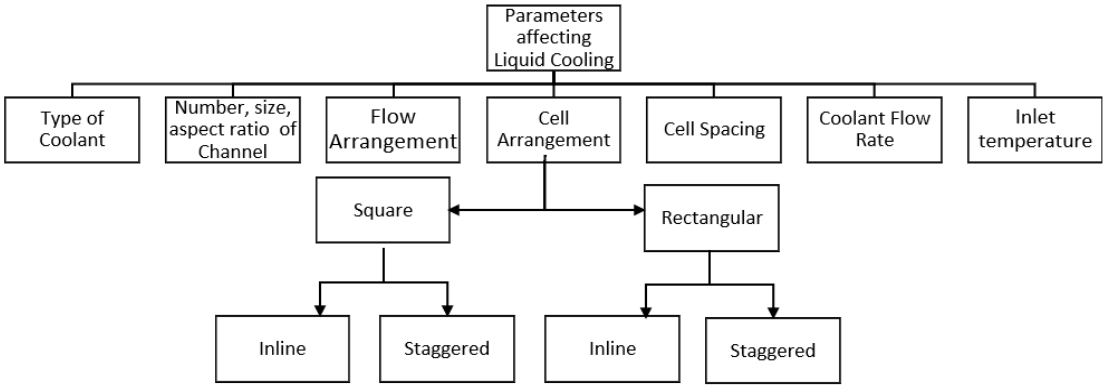


Fig. 13. Parameters related to the design and performance of Liquid-based cooling system for EV battery

For liquid cooling , the temporal variation of 'T_S' can be calculated by solving the conservation of mass , momentum and energy equations for 2-dimensional flow as given in section 3.2 (Eq. (6) to Eq. (10)) with appropriate use of properties of liquid coolant instead of air coolant [57].

4.3 PCM based Cooling

Solid-liquid PCM based cooling have received a plenty of attention by the researchers because of their ability to absorb latent heat of fusion during melting and passive nature. When the cell surface temperature reaches to the melting point of PCM it starts absorbing latent heat from the cell, maintaining its temperature close to its melting point. Conventionally, the use of PCM has been extensively researched for space cooling and thermal energy storage applications [67-70]. However, PCM-based cooling has recently received a lot of attention for battery cooling applications. Table 4 highlights the major research findings of this method.

It is seen that with PCM in most of the cases the 'T_{max}' inside the battery can be kept well below 45°C and 'ΔT_{max}' less than or equal to 6 °C with discharge rates up to 3C. Furthermore, in most of the cases the 'T_{max}' is maintained close to the melting temperature of the PCM. The researchers also investigated a combination of passive cooling (PCM) and active cooling techniques like PCM-air, PCM-liquid, PCM-heat pipe and discovered that these hybrid systems performed better in terms of temperature uniformity and the highest temperature inside the battery pack in comparison with the baseline systems [24,25]. However in a comparative numerical analysis, of batteries between (PCM) and forced air circulation methods, it is discovered that the cold air from the cabin AC was more effective than PCM at keeping the battery temperature within a safe range and at increasing the cycle life even at high ambient temperature (Figure 14). But, PCM cooling was found to be more effective than air cooling in maintaining temperature uniformity within the pack [82].

Table 4
Comparison of PCM- Based Thermal Management systems

Thermal Management system	Type of investigation	Melting Point	Cell Chemistry	Discharge rate	T_{max} (°C)	ΔT_{max} (°C)
PCM + Metal Foam + air [71]	Numerical	27 °C	LFP	2 C	28.1 °C	5.2 °C
PCM + liquid [72]	Numerical	42°C – 45°C 41°C – 43°C	LCO	0.5 C, 3C,	20°C,44°C,47°C	1 °C, 4 °C, and 6 °C
PCM-fin [73]	Numerical	44°C 50°C, 54°C	LFP	1C,1.5C,2C,3C	57.2 ° C	< 5 ° C
PCM + Water [74]	Numerical	27˚C	NMC	0.5C, 1C 1.5C	35 ° C	8 ° C
PCM + liquid [75]	Numerical	36.7 ° C, 40.2 ° C, 44.5 ° C	LFP	2C	39 to 52 ° C	6 ° C
PCM + Fin [76]	Numerical	42 to 44 ° C	LFP	2C	54.6 ° C	6 ° C
PCM + liquid [77]	Numerical	41 to 44 ° C	MNC	5C	45.24 ° C	3.49 ° C
PCM-Air [78]	Experimental	27 to 28 ° C	NMC	2.5C	40 ° C	2.4 ° C
PCM-Air [79]	Numerical	28	LFP	1C, 2C, 5C	34.77 ° C	< 4 ° C
PCM-Air [80]	Numerical	29 ° C	LCO	1C, 4C	30.5 °C	6 ° C
PCM + graphene nanoparticles-Air [81]	Numerical	29 ° C	LCO	1C, 4C	29.5 °C	Single cell

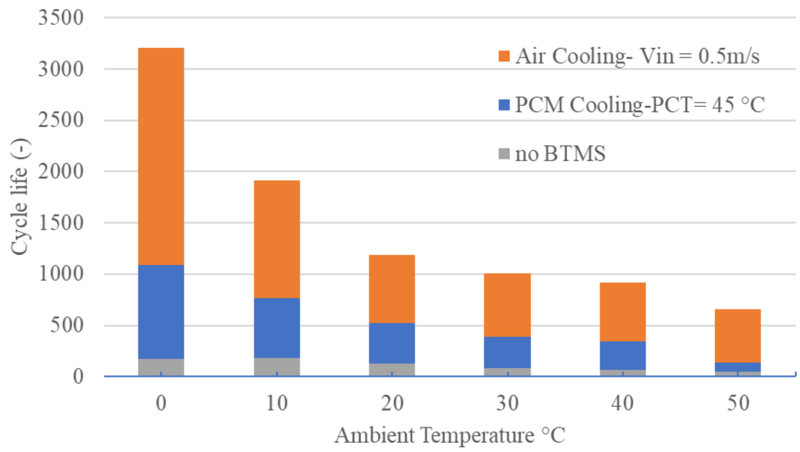


Fig. 14. Comparison of cycle life of battery with air cooling, PCM cooling and no BTMS [82]

Among the parameters which can be varied for optimizing the PCM-based cooling are chemical composition, melting point, shape of encapsulation (circular, square, polygonal etc.), PCM layer thickness, number of fins [83-89].

Based on the studied literature, we may deduce that the maximum temperature inside a battery is directly related to the melting temperature of the PCM. A lower melting point leads to lower maximum temperature, but it can cause rapid solid phase exhaustion and sensible heat transfer thereafter. High melting point PCMs last longer but maintain higher 'T_{max}'. PCM-based BTMS must have an air or liquid-based cooling provision to solidify the PCM, which consumes power.

4.4 Heat Pipe based Cooling

Heat pipes are passive heat transfer devices which use liquid-vapor phase-change process to transfer heat from one location to another. They consist of an evaporator section, a condenser section, and a wick structure that transports the working fluid (Figure 15). The working fluid evaporates in response to applied heat in the evaporator section, absorbing the latent heat of vaporization before transferring it to the condenser section, where it condenses and releases it back [90]. In battery cooling applications the evaporator section is placed touching with the surface of battery and the condenser section in the heat sink which is cooled by forced circulation.

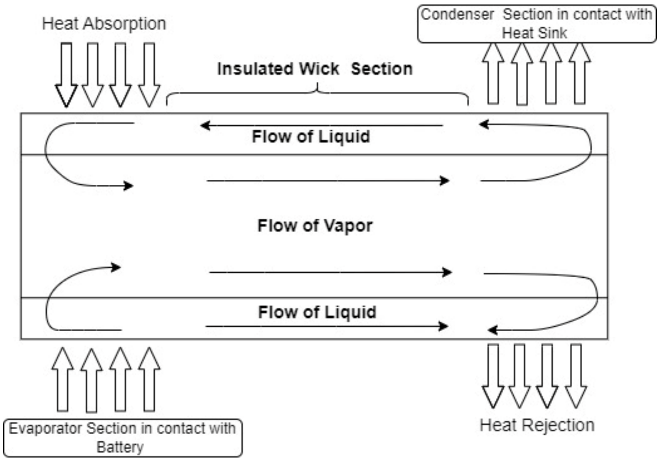


Fig. 15. Schematic of application of heat pipe for battery cooling

Water-based heat pipes can dissipate approximately 20 W of heat, lowering surface temperature and temperature drop [91]. Heat pipes with L- and I-shapes can maintain an output temperature of less than 55ºC and a temperature differential of less than 5ºC while consuming the highest input power [92]. Flat heat pipe (heat mat) technology can extend battery life and capacity by reducing ageing and degradation [93]. Researchers have examined factors like heat pipe orientation, type of working fluid, and dimensions (such as length and diameter) in order to improve heat pipe performance [88,93-97]. Researchers are also incorporating nano particles into the working fluid to improve heat pipe performance for battery cooling applications [98]. It is found that the batter temperature can be reduced by about 10% by using heat pipe [99].

We may deduce from the literature survey presented in this section that a 'BTMS' based on heat pipes can keep the cell temperature below 40°C and the 'ΔT_{max}' in the pack well below the 5 °C mark. However, more research is needed to optimize the design and operation of heat pipe-based 'BTMS', use of advanced materials and working fluids, and to investigate how they interact with other thermal management technologies.

4.5 Non-conventional Cooling Techniques

Recently, some non-conventional cooling techniques such as evaporative cooling, mist cooling, jet impingement cooling have stimulated the interest of researchers for their studies related to BTMS.

4.5.1 Evaporative cooling

This cooling technique is gaining attention as a potential future for optimizing and enhancing the air-cooling systems. In evaporative cooling water held in the pours of cooling pad gets vaporised by absorbing the required latent heat from the air passing through it. Figure 16 depicts a typical evaporative cooling arrangement implemented for battery cooling.

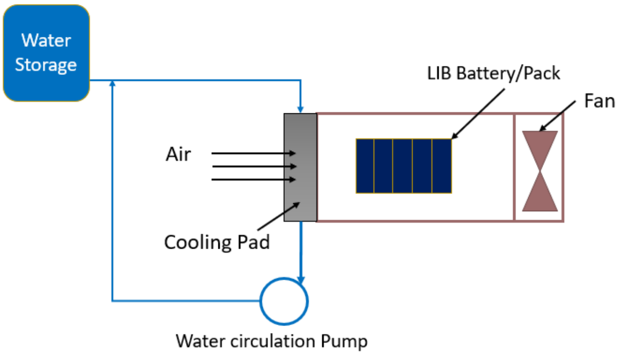


Fig. 16. Typical evaporative cooling system for battery-cooling application

Cooling pad (wetted porous medium) is the vital component of evaporative cooling system. These are available in variety of materials , geometrical configurations and thicknesses as seen in the Figure 17, for e.g. vegetable fibres (Jute, Khus, coconut, cellulose), Textile fibres (Cotton, synthetic fabric), Paper, Wood (Bamboo, wood chips/ shaving), Plastic (PVC sponge, plastic mech), Ceramic (Porous ceramic tubes/plates), Metal, Copper Metal Foam [100].

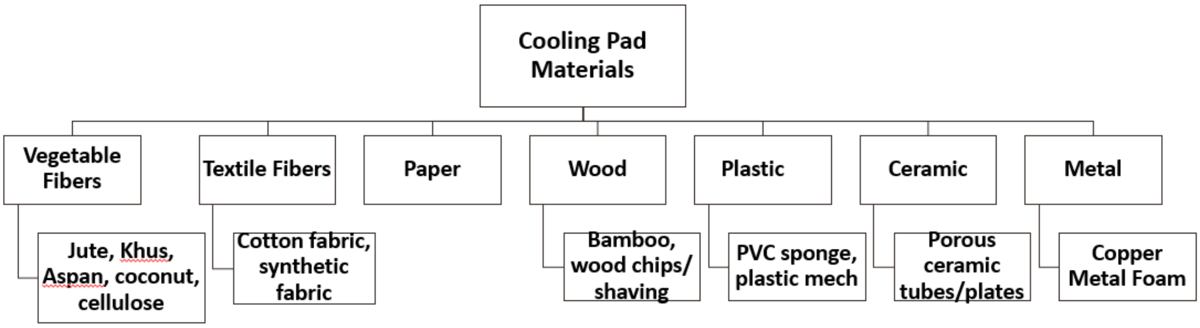


Fig. 17. Materials used for cooling pad in evaporative cooling

Youssef *et al.,* [101] conducted experiments on a 50 Ah prismatic battery with an evaporative cooling system integrated with jute fibre as a cooling pad material. The results showed that jute enhances air cooling performance by improving temperature uniformity and reducing equipment weight. A hybrid cooling concept for battery applications used capillary effect to draw water coolant from the reservoir, consuming no more power than air-cooling [102]. This improved efficiency and temperature consistency by over 70% and 56% respectively as compared to air cooling. The wick filter-based direct evaporative cooling (DEC) developed by Zhao *et al.,* [103] outperformed forced and natural convection air cooling in terms of peak battery temperatures, temperature disparities, and capacity deterioration. Ren *et al.,* [104] suggested a novel evaporative cooling in which a thin film of sodium alginate with a 99.9% water (SA-1 film) is applied to the battery surface (Figure 18). The findings revealed that under charge/discharge rates of more than 1 C, the temperature increase rate is cut in half.

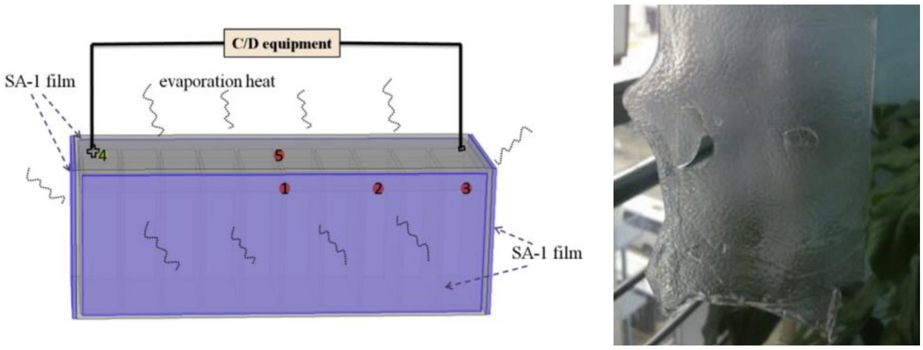


Fig. 18. Schematic of tested pack for the SA-1 film in the experiment [104]

4.5.2 Mist cooling

In this technique a mixture of fine water droplets and air (mist) is passed over the surface to be cooled. Saw *et al.,* [105] proposed mist cooling for 'BTMS' as shown in Figure 19. They found that the mist cooling at a mass flow rate of 5 g/s and a mist loading fraction of 3% is adequate to keep the battery surface temperature of the module below 40 °C [105]. When compared to dry air cooling, it can offer a more even temperature distribution as well.

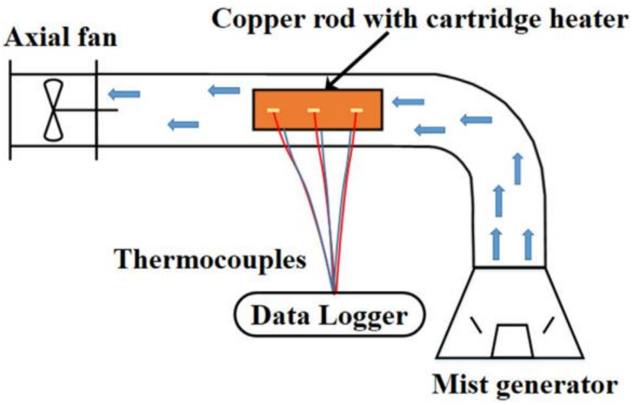


Fig. 19. (a) Schematic drawing of the cell test set-up with mist cooling [105]

4.5.3 Jet impingement cooling

Whether to cool the battery tabs or the cell surface is a topic of debate. According to Wang *et al.,* [106], the temperature of positive and negative current collector is higher than the cell-center temperature, so it is feasible to manage the cell temperature by cooling the tabs. Further it is found that at high discharge rates the usable capacity of surface cooled cell drops three times more than that of tab cooled cell [107]. A recent study comparing natural convection, forced convection, and tab cooling discovered that tab cooling produces 32.5% better uniformity of temperature than the other techniques [108]. Air Jet Impingement Cooling appears to be a suitable cooling method for battery tab cooling as it is capable of dissipating heat with extremely high rates per unit surface area [109]. It produces a thin boundary layer on a component surface, which results in improvement in both local and area-averaged heat transfer coefficients that are up to three times higher than conventional convection cooling [110]. Air pressure, Air Jet Velocity, Air nozzle diameter, Distance between jets, Distance between nozzle and surface, frequency of jet impingement are the design key parameters. There is relatively little literature on the use of the air jet impingement cooling approach for EV battery thermal management.

Zuckerman and Lior [111] presented the innovative concept of a combination of impinging jet and mainstream air cooling , to enhance hybrid car battery heat management. Their experimental and numerical results revealed that at varying impinging jet intake pressures, the average Nusselt number (Nu_{ave}) and maximum Nusselt number (Nu_{max}) both were augmented from 0.43 to16.55 and from 5.73 to 34.42, respectively.

The studied literature review suggests that the controlling parameters in evaporative cooling are the cooling pad (material, thickness and configuration), water evaporation rate, air flow rate, temperature, and humidity of the inlet air. In case of Air Jet Impingement Cooling the parameters are jet diameter, air velocity (Back Pressure), distance of jet outlet from tab, number of jets, pitch and frequency of air injection.

5. Comparative Analysis of Cooling Methods

A comparison of major cooling techniques is presented in Table 5 based on their relative advantages and drawbacks. It suggests that air cooling is the most cost-effective, lightweight, and simple option for cooling LIBs. However, it performs poorly in efficiency and temperature distribution. PCM-based cooling offers greater uniformity but is sensitive to melting point and may require a secondary cooling system. Heat pipe-based cooling is more efficient but may increase complexity. With more investigation, evaporative cooling could be employed as a balance between air and liquid cooling.

Table 5
A comparison of prominent battery cooling systems

Parameters/cooling system	Forced air cooling	Forced liquid cooling	PCM-cooling	Evaporative Cooling
Cooling Efficiency	Low due to poor heat transfer coefficient of air	High due to better heat transfer coefficient of liquid coolants	Maximum, due to latent heat absorption during phase change	Better than air cooling due to latent heat absorption by air from water
Cost and Complexity	Simple and cheap due to less number of components	Complex and costly due to more number of components and coolant lines running through battery pack	Simplest due to least number of components and moderate cost	More complexity and cost than air cooling due to inclusion of cooling pad and water circulation circuit
Energy consumption	High power consumption by fan/ blower [56]	Less energy consumption by pump/compressor compared to air cooling [56]	No or very less energy consumption in case of secondary cooling system	Water circulation system increases the energy consumption of baseline air cooling slightly
Weight	Components like fan/blower and passage-ways add to the system weight. Light weight	Components like pump/ compressor, tubes, coolant, heat exchangers adds to the system weight [112]. Heavy weight	Weight of PCM and secondary cooling components if used, add to system. Heavy weight	cooling pad and water circulation circuit adds weight. Heavier than air cooling
Maximum temperature of battery pack*	Affected by air flow rate, channel size, inlet temperature,	Influenced by properties and flow rate of coolant,	Affected by melting point, composition, latent heat of fusion	Affected by cooling pad material and

	location of fan and inlets/outlets. Typical value: 42.5°C (3C) [113]	number and size of channels, inlet temperature, flow arrangement [114] Typical value: 31.41 °C [115]	and thickness/type of PCM encapsulation, Typical value: 30.53 °C (3C) [113]	configuration, water circulation rate, humidity and temperature of ambient air Typical value: 37.5 °C (2.5C) [101]
Temperature uniformity within battery pack*	Poor, since air gets heated quickly as it flows due to it's low specific heat. Typical value: 7.4 °C [116]	Good, due to better heat absorbing capacity of liquid coolant Typical value: 3.46 °C [117]	Best, as PCM melts at a constant temperature Typical value: 4.1 °C [78]	Typical value: 4.1 °C [101]

*The maximum temperature and temperature uniformity gets affected by battery parameters like cell chemistry, number of cells, cell arrangement and discharge rates

6. Conclusion

This study provides a concise evaluation of several cooling systems proposed for EV batteries, as well as their benefits and drawbacks along with the causes of heat generation and the resulting thermal issues such as capacity fade, thermal runaway, and uneven temperature distribution. This review brings us to the following conclusions

i. Although the Joule heating (irreversible heating) dominates the heat generation most of the times, entropic heating (reversible heating) must also be considered especially during low discharge rates and high temperatures, the conditions that may exist while cruising on highways in hot weather.
ii. The causes of capacity fade such as increase in resistance to charge transfer at the anode due to the formation of a 'SEI' layer, increase in mass transfer resistance of the separator due to the accumulation of side reaction products and the depletion of active material at the negative electrode are temperature-dependent. This necessitates a cooling system for the battery that will keep its temperature within a narrow range of 15°C to 35°C and maintain the 'ΔT_{max}' below 6°C. To safeguard the battery from thermal runaway it should not be discharged at a temperature above 50°C particularly at elevated C-rates.
iii. Out of the most explored cooling methodologies, air cooling is found to be the best option when cost, weight, and simplicity as well as the availability of natural air steam, are taken into account. It has the benefit of ease of packaging, less maintenance cost, no risk leakage of fluids into electronic circuits, high reliability and high design flexibility. However, it performs poorly in terms of efficiency and temperature distribution.
iv. PCM-based cooling has a high heat-absorbing capacity and offers greater temperature uniformity, but it is heavy , sensitive to melting point, and needs a secondary cooling system. Heat pipe-based cooling has been found to be more compact and efficient, but it may increase system complexity and has limited heat absorbing capacity.
v. The most efficient in terms of temperature uniformity and peak temperature is the liquid cooling system, but it adds cost and complexity. Evaporative cooling may be a better option for air cooling because it can lower the temperature below ambient by absorbing latent heat of vaporization, but it requires more research before it can be put into practical applications.

Advancements in EVs have led to LIBs as a preferred alternative to conventional power sources. The demand for longer range and fast charging is increasing. As commercial vehicles and trains become electrified, the power demand from EV batteries will increase, necessitating advanced technologies to address thermal challenges. Table 6 summarizes the future research directions.

Table 6
Future research projections in BTMS

Type of EV	Currently used cooling system	Future research prospectus
Bikes and rikshaws	Natural or forced air circulation	PCM, heat pipe, submerged liquid, hybrid, IP67 regulations compliance
Cars	Forced Air, Liquid cooling	Hybrid cooling, energy consumption optimization
Trucks and buses	Forced Liquid cooling	Hybrid cooling, jet impingement, evaporative cooling, energy consumption optimization

Evaporative cooling is one of the promising methods for dissipating the enormous heat generated in these high-density battery packs because it can absorb a large amount of heat while adding little to the complexity of the system.

Commercial vehicles and trains that use compressed air for pneumatic braking have an in-built source of pressurised air. So, air jet impingement cooling due to their very high heat transfer coefficients could be a viable option for cooling the tabs of commercial EV battery packs.

Most two-wheeler electric vehicles lack a cooling system for their batteries, necessitating the development of suitable cooling systems for bikes and scooters considering the space, weight and power consumption constraints. Compliance with IP67 regulations which restricts air flow into battery packs, also imposes challenges before the researchers temperature. Further, submerged cooling systems or PCM-based cooling systems may also be explored for electric bikes.

Last but not the least, since the energy needed to run the cooling system comes from the battery that powers the EV , the range of an EV gets affected. Therefore, the energy consumption of the cooling system is an issue. Future research may focus on creating ever-more energy-efficient cooling systems that meet the battery's precise cooling needs based on its operating modes.

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References
[1] Lin, Jiayuan, Xinhua Liu, Shen Li, Cheng Zhang, and Shichun Yang. "A review on recent progress, challenges and perspective of battery thermal management system." *International Journal of Heat and Mass Transfer* 167 (2021): 120834. https://doi.org/10.1016/j.ijheatmasstransfer.2020.120834
[2] Wen, Jianping, Dan Zhao, and Chuanwei Zhang. "An overview of electricity powered vehicles: Lithium-ion battery energy storage density and energy conversion efficiency." *Renewable Energy* 162 (2020): 1629-1648. https://doi.org/10.1016/j.renene.2020.09.055
[3] Dincer, Ibrahim, Halil S. Hamut, and Nader Javani. *Thermal management of electric vehicle battery systems*. John Wiley & Sons, 2016. https://doi.org/10.1002/9781118900239
[4] Abd Aziz, Mohd Azri, Mohd Saifizi Saidon, Muhammad Izuan Fahmi Romli, Siti Marhainis Othman, Wan Azani Mustafa, Mohd Rizal Manan, and Muhammad Zaid Aihsan. "A Review on BLDC Motor Application in Electric Vehicle (EV) using Battery, Supercapacitor and Hybrid Energy Storage System: Efficiency and Future Prospects." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 30, no. 2 (2023): 41-59. https://doi.org/10.37934/araset.30.2.4159
[5] Nzereogu, P. U., A. D. Omah, F. I. Ezema, E. I. Iwuoha, and A. C. Nwanya. "Anode materials for lithium-ion batteries: A review." *Applied Surface Science Advances* 9 (2022): 100233. https://doi.org/10.1016/j.apsadv.2022.100233

[6] Shah, Krishna, Divya Chalise, and Ankur Jain. "Experimental and theoretical analysis of a method to predict thermal runaway in Li-ion cells." *Journal of Power Sources* 330 (2016): 167-174. https://doi.org/10.1016/j.jpowsour.2016.08.133
[7] Gao, Qing, Yubin Liu, Guohua Wang, Fan Deng, and Jichen Zhu. "An experimental investigation of refrigerant emergency spray on cooling and oxygen suppression for overheating power battery." *Journal of Power Sources* 415 (2019): 33-43. https://doi.org/10.1016/j.jpowsour.2019.01.052
[8] Sato, Noboru. "Thermal behavior analysis of lithium-ion batteries for electric and hybrid vehicles." *Journal of Power Sources* 99, no. 1-2 (2001): 70-77. https://doi.org/10.1016/S0378-7753(01)00478-5
[9] Tete, Pranjali R., Mahendra M. Gupta, and Sandeep S. Joshi. "Developments in battery thermal management systems for electric vehicles: A technical review." *Journal of Energy Storage* 35 (2021): 102255. https://doi.org/10.1016/j.est.2021.102255
[10] Bernardi, D., E. Pawlikowski, and John Newman. "A general energy balance for battery systems." *Journal of the Electrochemical Society* 132, no. 1 (1985): 5. https://doi.org/10.1149/1.2113792
[11] Yang, Shi-chun, Yang Hua, Dan Qiao, Yu-bo Lian, Yu-wei Pan, and Yong-ling He. "A coupled electrochemical-thermal-mechanical degradation modelling approach for lifetime assessment of lithium-ion batteries." *Electrochimica Acta* 326 (2019): 134928. https://doi.org/10.1016/j.electacta.2019.134928
[12] Eddahech, Akram, Olivier Briat, and Jean-Michel Vinassa. "Thermal characterization of a high-power lithium-ion battery: Potentiometric and calorimetric measurement of entropy changes." *Energy* 61 (2013): 432-439. https://doi.org/10.1016/j.energy.2013.09.028
[13] Liu, Guangming, Minggao Ouyang, Languang Lu, Jianqiu Li, and Xuebing Han. "Analysis of the heat generation of lithium-ion battery during charging and discharging considering different influencing factors." *Journal of Thermal Analysis and Calorimetry* 116 (2014): 1001-1010. https://doi.org/10.1007/s10973-013-3599-9
[14] Park, Chanwoo, and Arun K. Jaura. *Dynamic thermal model of li-ion battery for predictive behavior in hybrid and fuel cell vehicles*. No. 2003-01-2286. SAE Technical Paper, 2003. https://doi.org/10.4271/2003-01-2286
[15] De Vita, Armando, Arpit Maheshwari, Matteo Destro, Massimo Santarelli, and Massimiliana Carello. "Transient thermal analysis of a lithium-ion battery pack comparing different cooling solutions for automotive applications." *Applied Energy* 206 (2017): 101-112. https://doi.org/10.1016/j.apenergy.2017.08.184
[16] Lai, Yanqing, Shuanglong Du, Liang Ai, Lihua Ai, Yun Cheng, Yiwei Tang, and Ming Jia. "Insight into heat generation of lithium ion batteries based on the electrochemical-thermal model at high discharge rates." *International Journal of Hydrogen Energy* 40, no. 38 (2015): 13039-13049. https://doi.org/10.1016/j.ijhydene.2015.07.079
[17] Lu, Z., X. L. Yu, L. C. Wei, F. Cao, L. Y. Zhang, X. Z. Meng, and L. W. Jin. "A comprehensive experimental study on temperature-dependent performance of lithium-ion battery." *Applied Thermal Engineering* 158 (2019): 113800. https://doi.org/10.1016/j.applthermaleng.2019.113800
[18] Singh, Lalan K., G. Mishra, A. K. Sharma, and Anoop K. Gupta. "A numerical study on thermal management of a lithium-ion battery module via forced-convective air cooling." *International Journal of Refrigeration* 131 (2021): 218-234. https://doi.org/10.1016/j.ijrefrig.2021.07.031
[19] Kang, Jianqiang, and Giorgio Rizzoni. "Study of relationship between temperature and thermal energy, operating conditions as well as environmental factors in large-scale lithium-ion batteries." *International Journal of Energy Research* 38, no. 15 (2014): 1994-2002. https://doi.org/10.1002/er.3212
[20] Roscher, Michael A., Jens Vetter, and Dirk Uwe Sauer. "Characterisation of charge and discharge behaviour of lithium ion batteries with olivine based cathode active material." *Journal of Power Sources* 191, no. 2 (2009): 582-590. https://doi.org/10.1016/j.jpowsour.2009.02.024
[21] Cheng, Jian-liang, Xin-hai Li, Zhi-xing Wang, and Hua-jun Guo. "Mechanism for capacity fading of 18650 cylindrical lithium ion batteries." *Transactions of Nonferrous Metals Society of China* 27, no. 7 (2017): 1602-1607. https://doi.org/10.1016/S1003-6326(17)60182-1
[22] Ye, Yonghuang, Yixiang Shi, and Andrew A. O. Tay. "Electro-thermal cycle life model for lithium iron phosphate battery." *Journal of Power Sources* 217 (2012): 509-518. https://doi.org/10.1016/j.jpowsour.2012.06.055
[23] Plett, Gregory L. *Battery management systems, Volume I: Battery modeling. Vol. 1*. Artech House, 2015.
[24] Heiskanen, Satu Kristiina, Jongjung Kim, and Brett L. Lucht. "Generation and evolution of the solid electrolyte interphase of lithium-ion batteries." *Joule* 3, no. 10 (2019): 2322-2333. https://doi.org/10.1016/j.joule.2019.08.018
[25] Maures, Matthieu, Yuanci Zhang, Cyril Martin, J-Y. Delétage, J-M. Vinassa, and Olivier Briat. "Impact of temperature on calendar ageing of Lithium-ion battery using incremental capacity analysis." *Microelectronics Reliability* 100 (2019): 113364. https://doi.org/10.1016/j.microrel.2019.06.056
[26] Motloch, Chester G., Jon P. Christophersen, Jeffrey R. Belt, Randy B. Wright, Gary L. Hunt, Raymond A. Sutula, Tien Duong, Thomas J. Tartamella, Harold J. Haskins, and Ted J. Miller. *High-Power Battery Testing Procedures and Analytical Methodologies for HEV's*. No. 2002-01-1950. SAE Technical Paper, 2002. https://doi.org/10.4271/2002-01-1950

[27] Wu, Tangqin, Haodong Chen, Qingsong Wang, and Jinhua Sun. "Comparison analysis on the thermal runaway of lithium-ion battery under two heating modes." *Journal of Hazardous Materials* 344 (2018): 733-741. https://doi.org/10.1016/j.jhazmat.2017.11.022

[28] Kvasha, Andriy, César Gutiérrez, Urtzi Osa, Iratxe de Meatza, J. Alberto Blazquez, Haritz Macicior, and Idoia Urdampilleta. "A comparative study of thermal runaway of commercial lithium ion cells." *Energy* 159 (2018): 547-557. https://doi.org/10.1016/j.energy.2018.06.173

[29] Zhao, Chunpeng, Jinhua Sun, and Qingsong Wang. "Thermal runaway hazards investigation on 18650 lithium-ion battery using extended volume accelerating rate calorimeter." *Journal of Energy Storage* 28 (2020): 101232. https://doi.org/10.1016/j.est.2020.101232

[30] Feng, Xuning, Mou Fang, Xiangming He, Minggao Ouyang, Languang Lu, Hao Wang, and Mingxuan Zhang. "Thermal runaway features of large format prismatic lithium ion battery using extended volume accelerating rate calorimetry." *Journal of Power Sources* 255 (2014): 294-301. https://doi.org/10.1016/j.jpowsour.2014.01.005

[31] Liu, Xiang, Dongsheng Ren, Hungjen Hsu, Xuning Feng, Gui-Liang Xu, Minghao Zhuang, Han Gao et al. "Thermal runaway of lithium-ion batteries without internal short circuit." *Joule* 2, no. 10 (2018): 2047-2064. https://doi.org/10.1016/j.joule.2018.06.015

[32] Friesen, Alex, Fabian Horsthemke, Xaver Mönnighoff, Gunther Brunklaus, Roman Krafft, Markus Börner, Tim Risthaus, Martin Winter, and Falko M. Schappacher. "Impact of cycling at low temperatures on the safety behavior of 18650-type lithium ion cells: Combined study of mechanical and thermal abuse testing accompanied by post-mortem analysis." *Journal of Power Sources* 334 (2016): 1-11. https://doi.org/10.1016/j.jpowsour.2016.09.120

[33] Huang, Qian, Manming Yan, and Zhiyu Jiang. "Thermal study on single electrodes in lithium-ion battery." *Journal of Power Sources* 156, no. 2 (2006): 541-546. https://doi.org/10.1016/j.jpowsour.2005.05.083

[34] Korthauer, Reiner, ed. *Lithium-ion batteries: basics and applications*. Springer, 2018. https://doi.org/10.1007/978-3-662-53071-9

[35] Yang, Ruoyu, Meiwei Wang, and Huan Xi. "Thermal investigation and forced air-cooling strategy of battery thermal management system considering temperature non-uniformity of battery pack." *Applied Thermal Engineering* 219 (2023): 119566. https://doi.org/10.1016/j.applthermaleng.2022.119566

[36] Shahid, Seham, and Martin Agelin-Chaab. "Analysis of cooling effectiveness and temperature uniformity in a battery pack for cylindrical batteries." *Energies* 10, no. 8 (2017): 1157. https://doi.org/10.3390/en10081157

[37] Shi, Shang, Yongqi Xie, Ming Li, Yanping Yuan, Jianzu Yu, Hongwei Wu, Bin Liu, and Nan Liu. "Non-steady experimental investigation on an integrated thermal management system for power battery with phase change materials." *Energy Conversion and Management* 138 (2017): 84-96. https://doi.org/10.1016/j.enconman.2017.01.069

[38] Huang, Yuqi, Yiji Lu, Rui Huang, Junxuan Chen, Fenfang Chen, Zhentao Liu, Xiaoli Yu, and Anthony Paul Roskilly. "Study on the thermal interaction and heat dissipation of cylindrical Lithium-Ion Battery cells." *Energy Procedia* 142 (2017): 4029-4036. https://doi.org/10.1016/j.egypro.2017.12.321

[39] Liu, Huaqiang, Zhongbao Wei, Weidong He, and Jiyun Zhao. "Thermal issues about Li-ion batteries and recent progress in battery thermal management systems: A review." *Energy Conversion and Management* 150 (2017): 304-330. https://doi.org/10.1016/j.enconman.2017.08.016

[40] Pesaran, Ahmad A. "Battery thermal models for hybrid vehicle simulations." *Journal of Power Sources* 110, no. 2 (2002): 377-382. https://doi.org/10.1016/S0378-7753(02)00200-8

[41] Chatterjee, Krishnashis, Pradip Majumdar, David Schroeder, and S. Rao Kilaparti. "Performance analysis of Li-ion battery under various thermal and load conditions." *Journal of Electrochemical Energy Conversion and Storage* 16, no. 2 (2019): 021006. https://doi.org/10.1115/1.4041983

[42] Pesaran, Ahmad A. *Tools for designing thermal management of batteries in electric drive vehicles*. National Renewable Energy Laboratory, 2013. https://doi.org/10.2172/1064502

[43] Pesaran, Ahmad A., Andreas Vlahinos, and Steven D. Burch. *Thermal performance of EV and HEV battery modules and packs*. Golden, CO, USA: National Renewable Energy Laboratory, 1997.

[44] Ladrech, F. "Battery thermal management for HEV & EV-Technology overview." *Proceedings of the Automotive Summit, Brussels, Belgium* 10 (2010).

[45] Zhao, Gang, Xiaolin Wang, Michael Negnevitsky, and Hengyun Zhang. "A review of air-cooling battery thermal management systems for electric and hybrid electric vehicles." *Journal of Power Sources* 501 (2021): 230001. https://doi.org/10.1016/j.jpowsour.2021.230001

[46] Wang, Qian, Bin Jiang, Bo Li, and Yuying Yan. "A critical review of thermal management models and solutions of lithium-ion batteries for the development of pure electric vehicles." *Renewable and Sustainable Energy Reviews* 64 (2016): 106-128. https://doi.org/10.1016/j.rser.2016.05.033

[47] Wang, Tao, K. J. Tseng, Jiyun Zhao, and Zhongbao Wei. "Thermal investigation of lithium-ion battery module with different cell arrangement structures and forced air-cooling strategies." *Applied Energy* 134 (2014): 229-238.

https://doi.org/10.1016/j.apenergy.2014.08.013

[48] Lu, Zhao, Xiaoling Yu, Lichuan Wei, Yalin Qiu, Liyu Zhang, Xiangzhao Meng, and Liwen Jin. "Parametric study of forced air cooling strategy for lithium-ion battery pack with staggered arrangement." *Applied Thermal Engineering* 136 (2018): 28-40. https://doi.org/10.1016/j.applthermaleng.2018.02.080

[49] Chen, Kai, Weixiong Wu, Fang Yuan, Lin Chen, and Shuangfeng Wang. "Cooling efficiency improvement of air-cooled battery thermal management system through designing the flow pattern." *Energy* 167 (2019): 781-790. https://doi.org/10.1016/j.energy.2018.11.011

[50] Zhang, Furen, Pengwei Wang, and Mengfei Yi. "Design optimization of forced air-cooled lithium-ion battery module based on multi-vents." *Journal of Energy Storage* 40 (2021): 102781. https://doi.org/10.1016/j.est.2021.102781

[51] Fan, Yuqian, Yun Bao, Chen Ling, Yanyan Chu, Xiaojun Tan, and Shuting Yang. "Experimental study on the thermal management performance of air cooling for high energy density cylindrical lithium-ion batteries." *Applied Thermal Engineering* 155 (2019): 96-109. https://doi.org/10.1016/j.applthermaleng.2019.03.157

[52] Kang, Deokhun, Pyeong-Yeon Lee, Kisoo Yoo, and Jonghoon Kim. "Internal thermal network model-based inner temperature distribution of high-power lithium-ion battery packs with different shapes for thermal management." *Journal of Energy Storage* 27 (2020): 101017. https://doi.org/10.1016/j.est.2019.101017

[53] Widyantara, Robby Dwianto, Muhammad Adnan Naufal, Poetro Lebdo Sambegoro, Ignatius Pulung Nurprasetio, Farid Triawan, Djati Wibowo Djamari, Asep Bayu Dani Nandiyanto, Bentang Arief Budiman, and Muhammad Aziz. "Low-cost air-cooling system optimization on battery pack of electric vehicle." *Energies* 14, no. 23 (2021): 7954. https://doi.org/10.3390/en14237954

[54] Chen, Kai, Yiming Chen, Yiqi She, Mengxuan Song, Shuangfeng Wang, and Lin Chen. "Construction of effective symmetrical air-cooled system for battery thermal management." *Applied Thermal Engineering* 166 (2020): 114679. https://doi.org/10.1016/j.applthermaleng.2019.114679

[55] Zhang, Furen, Aizhen Lin, Pengwei Wang, and Peiwen Liu. "Optimization design of a parallel air-cooled battery thermal management system with spoilers." *Applied Thermal Engineering* 182 (2021): 116062. https://doi.org/10.1016/j.applthermaleng.2020.116062

[56] Chen, Dafen, Jiuchun Jiang, Gi-Heon Kim, Chuanbo Yang, and Ahmad Pesaran. "Comparison of different cooling methods for lithium ion battery cells." *Applied Thermal Engineering* 94 (2016): 846-854. https://doi.org/10.1016/j.applthermaleng.2015.10.015

[57] Saechan, Patcharin, and Isares Dhuchakallaya. "Numerical study on the air-cooled thermal management of Lithium-ion battery pack for electrical vehicles." *Energy Reports* 8 (2022): 1264-1270. https://doi.org/10.1016/j.egyr.2021.11.089

[58] Wang, Jianguo, Shuai Lu, Yingzhou Wang, Chenyu Li, and Kairang Wang. "Effect analysis on thermal behavior enhancement of lithium-ion battery pack with different cooling structures." *Journal of Energy Storage* 32 (2020): 101800. https://doi.org/10.1016/j.est.2020.101800

[59] Wang, Haitao, Tao Tao, Jun Xu, Xuesong Mei, Xiaoyan Liu, and Piao Gou. "Cooling capacity of a novel modular liquid-cooled battery thermal management system for cylindrical lithium ion batteries." *Applied Thermal Engineering* 178 (2020): 115591. https://doi.org/10.1016/j.applthermaleng.2020.115591

[60] Huang, Yuqi, Shun Wang, Yiji Lu, Rui Huang, and Xiaoli Yu. "Study on a liquid cooled battery thermal management system pertaining to the transient regime." *Applied Thermal Engineering* 180 (2020): 115793. https://doi.org/10.1016/j.applthermaleng.2020.115793

[61] Cen, Jiwen, Zhibin Li, and Fangming Jiang. "Experimental investigation on using the electric vehicle air conditioning system for lithium-ion battery thermal management." *Energy for Sustainable Development* 45 (2018): 88-95. https://doi.org/10.1016/j.esd.2018.05.005

[62] Shen, Ming, and Qing Gao. "System simulation on refrigerant-based battery thermal management technology for electric vehicles." *Energy Conversion and Management* 203 (2020): 112176. https://doi.org/10.1016/j.enconman.2019.112176

[63] Shen, Ming, and Qing Gao. "Structure design and effect analysis on refrigerant cooling enhancement of battery thermal management system for electric vehicles." *Journal of Energy Storage* 32 (2020): 101940. https://doi.org/10.1016/j.est.2020.101940

[64] Akbarzadeh, Mohsen, Theodoros Kalogiannis, Joris Jaguemont, Lu Jin, Hamidreza Behi, Danial Karimi, Hamidreza Beheshti, Joeri Van Mierlo, and Maitane Berecibar. "A comparative study between air cooling and liquid cooling thermal management systems for a high-energy lithium-ion battery module." *Applied Thermal Engineering* 198 (2021): 117503. https://doi.org/10.1016/j.applthermaleng.2021.117503

[65] Ding, Yuzhang, Minxiang Wei, and Rui Liu. "Channel parameters for the temperature distribution of a battery thermal management system with liquid cooling." *Applied Thermal Engineering* 186 (2021): 116494. https://doi.org/10.1016/j.applthermaleng.2020.116494

[66] Lyu, Y., A. R. M. Siddique, Shaikh Hasibul Majid, M. Biglarbegian, S. A. Gadsden, and Sahabi Mahmud. "Electric

vehicle battery thermal management system with thermoelectric cooling." *Energy Reports* 5 (2019): 822-827. https://doi.org/10.1016/j.egyr.2019.06.016

[67] Khan, Majid, Muhammad Ibrahim, and Tareq Saeed. "Space cooling achievement by using lower electricity in hot months through introducing PCM-enhanced buildings." *Journal of Building Engineering* 53 (2022): 104506. https://doi.org/10.1016/j.jobe.2022.104506

[68] Roy, Anindita, Ummid Shaikh, Sonali Kale, and Anirban Sur. "Performance Analysis of an Energy-Efficient PCM-Based Room Cooling System." *Frontiers in Heat and Mass Transfer (FHMT)* 20 (2023). https://doi.org/10.5098/hmt.20.28

[69] Sidik, Nor Azwadi Che, Tung Hao Kean, Hoong Kee Chow, Aravinthan Rajaandra, Saidur Rahman, and Jesbains Kaur. "Performance enhancement of cold thermal energy storage system using nanofluid phase change materials: a review." *International Communications in Heat and Mass Transfer* 94 (2018): 85-95. https://doi.org/10.1016/j.icheatmasstransfer.2018.03.024

[70] Gadhave, Pitambar, Firojkhan Pathan, Sandeep Kore, and Chandrakant Prabhune. "Comprehensive review of phase change material based latent heat thermal energy storage system." *International Journal of Ambient Energy* 43, no. 1 (2022): 4181-4206. https://doi.org/10.1080/01430750.2021.1873848

[71] Barnes, Derek, and Xianglin Li. "Battery thermal management using phase change material-metal foam composite materials at various environmental temperatures." *Journal of Electrochemical Energy Conversion and Storage* 17, no. 2 (2020): 021106. https://doi.org/10.1115/1.4045326

[72] Lopez, Carlos F., Judith A. Jeevarajan, and Partha P. Mukherjee. "Evaluation of combined active and passive thermal management strategies for lithium-ion batteries." *Journal of Electrochemical Energy Conversion and Storage* 13, no. 3 (2016): 031007. https://doi.org/10.1115/1.4035245

[73] Ping, Ping, Rongqi Peng, Depeng Kong, Guoming Chen, and Jennifer Wen. "Investigation on thermal management performance of PCM-fin structure for Li-ion battery module in high-temperature environment." *Energy Conversion and Management* 176 (2018): 131-146. https://doi.org/10.1016/j.enconman.2018.09.025

[74] Jin, Lu, Jun Tian, Shen Gao, Peng Xie, Mohsen Akbarzadeh, Theodoros Kalogiannis, Maitane Berecibar et al. "A novel hybrid thermal management approach towards high-voltage battery pack for electric vehicles." *Energy Conversion and Management* 247 (2021): 114676. https://doi.org/10.1016/j.enconman.2021.114676

[75] Bai, Fanfei, Mingbiao Chen, Wenji Song, Ziping Feng, Yongliang Li, and Yulong Ding. "Thermal management performances of PCM/water cooling-plate using for lithium-ion battery module based on non-uniform internal heat source." *Applied Thermal Engineering* 126 (2017): 17-27. https://doi.org/10.1016/j.applthermaleng.2017.07.141

[76] Verma, Ashima, and Dibakar Rakshit. "Performance analysis of PCM-fin combination for heat abatement of Li-ion battery pack in electric vehicles at high ambient temperature." *Thermal Science and Engineering Progress* 32 (2022): 101314. https://doi.org/10.1016/j.tsep.2022.101314

[77] Xin, Qianqian, Jinsheng Xiao, Tianqi Yang, Hengyun Zhang, and Xi Long. "Thermal management of lithium-ion batteries under high ambient temperature and rapid discharging using composite PCM and liquid cooling." *Applied Thermal Engineering* 210 (2022): 118230. https://doi.org/10.1016/j.applthermaleng.2022.118230

[78] Youssef, Rekabra, Md Sazzad Hosen, Jiacheng He, AL-Saadi Mohammed, Joeri Van Mierlo, and Maitane Berecibar. "Novel design optimization for passive cooling PCM assisted battery thermal management system in electric vehicles." *Case Studies in Thermal Engineering* 32 (2022): 101896. https://doi.org/10.1016/j.csite.2022.101896

[79] Singh, Lalan K., Anoop K. Gupta, and A. K. Sharma. "Hybrid thermal management system for a lithium-ion battery module: Effect of cell arrangement, discharge rate, phase change material thickness and air velocity." *Journal of Energy Storage* 52 (2022): 104907. https://doi.org/10.1016/j.est.2022.104907

[80] Akkurt, Nevzat, S. Aghakhani, Mustafa Z. Mahmoud, and ElSayed M. Tag El Din. "The influence of battery distance on a hybrid air-cooled cylindrical lithium-ion battery phase change material thermal management system for storing solar energy." *Journal of Energy Storage* 52 (2022): 104873. https://doi.org/10.1016/j.est.2022.104873

[81] Khan, M. N., Hayder A. Dhahad, Sagr Alamri, Ali E. Anqi, Kamal Sharma, Sadok Mehrez, Mohamed A. Shamseldin, and Banar Fareed Ibrahim. "Air cooled lithium-ion battery with cylindrical cell in phase change material filled cavity of different shapes." *Journal of Energy Storage* 50 (2022): 104573. https://doi.org/10.1016/j.est.2022.104573

[82] Chen, Fenfang, Rui Huang, Chongming Wang, Xiaoli Yu, Huijun Liu, Qichao Wu, Keyu Qian, and Rohit Bhagat. "Air and PCM cooling for battery thermal management considering battery cycle life." *Applied Thermal Engineering* 173 (2020): 115154. https://doi.org/10.1016/j.applthermaleng.2020.115154

[83] Srivastava, Gaurav, Rakesh Nandan, and Mihir Kumar Das. "Thermal runaway management of Li ion battery using PCM: A parametric study." *Energy Conversion and Management: X* 16 (2022): 100306. https://doi.org/10.1016/j.ecmx.2022.100306

[84] Huang, Qiqiu, Jian Deng, Xinxi Li, Guoqing Zhang, and Fei Xu. "Experimental investigation on thermally induced aluminum nitride based flexible composite phase change material for battery thermal management." *Journal of Energy Storage* 32 (2020): 101755. https://doi.org/10.1016/j.est.2020.101755

[85] Rajan, Joshwin T., Vinayak S. Jayapal, M. J. Krishna, KA Mohammed Firose, S. Vaisakh, Anish K. John, and Abhilash Suryan. "Analysis of battery thermal management system for electric vehicles using 1-tetradecanol phase change material." *Sustainable Energy Technologies and Assessments* 51 (2022): 101943. https://doi.org/10.1016/j.seta.2021.101943
[86] Alami, Abdul Hai, Hussein M. Maghrabie, Mohammad Ali Abdelkareem, Enas Taha Sayed, Zena Yasser, Tareq Salameh, S. M. A. Rahman, Hegazy Rezk, and A. G. Olabi. "Potential applications of phase change materials for batteries' thermal management systems in electric vehicles." *Journal of Energy Storage* 54 (2022): 105204. https://doi.org/10.1016/j.est.2022.105204
[87] Zhou, Zhizuan, Dong Wang, Yang Peng, Maoyu Li, Boxuan Wang, Bei Cao, and Lizhong Yang. "Experimental study on the thermal management performance of phase change material module for the large format prismatic lithium-ion battery." *Energy* 238 (2022): 122081. https://doi.org/10.1016/j.energy.2021.122081
[88] Liang, Jialin, Yunhua Gan, and Yong Li. "Investigation on the thermal performance of a battery thermal management system using heat pipe under different ambient temperatures." *Energy Conversion and Management* 155 (2018): 1-9. https://doi.org/10.1016/j.enconman.2017.10.063
[89] Liu, Huaqiang, Chuwen Jin, Hao Li, and Yulong Ji. "A numerical study of PCM battery thermal management performance enhancement with fin structures." *Energy Reports* 9 (2023): 1793-1802. https://doi.org/10.1016/j.egyr.2023.04.214
[90] Meseguer, José, Isabel Pérez-Grande, and Angel Sanz-Andrés. "11 - Heat pipes." *Spacecraft Thermal Control* (2012): 175-207. https://doi.org/10.1533/9780857096081.175
[91] Nasir, Faiza M., Mohd Z. Abdullah, and Mohd A. Ismail. "Experimental investigation of water-cooled heat pipes in the thermal management of lithium-ion EV batteries." *Arabian Journal for Science and Engineering* 44 (2019): 7541-7552. https://doi.org/10.1007/s13369-019-03851-5
[92] Mbulu, Hussein, Yossapong Laoonual, and Somchai Wongwises. "Experimental study on the thermal performance of a battery thermal management system using heat pipes." *Case Studies in Thermal Engineering* 26 (2021): 101029. https://doi.org/10.1016/j.csite.2021.101029
[93] Jouhara, Hussam, Nicolas Serey, Navid Khordehgah, Robert Bennett, Sulaiman Almahmoud, and Stephen P. Lester. "Investigation, development and experimental analyses of a heat pipe based battery thermal management system." *International Journal of Thermofluids* 1 (2020): 100004. https://doi.org/10.1016/j.ijft.2019.100004
[94] Wang, Qian, Bin Jiang, Q. F. Xue, H. L. Sun, Bo Li, H. M. Zou, and Y. Y. Yan. "Experimental investigation on EV battery cooling and heating by heat pipes." *Applied Thermal Engineering* 88 (2015): 54-60. https://doi.org/10.1016/j.applthermaleng.2014.09.083
[95] Ye, Yonghuang, Yixiang Shi, Lip Huat Saw, and Andrew A. O. Tay. "Performance assessment and optimization of a heat pipe thermal management system for fast charging lithium ion battery packs." *International Journal of Heat and Mass Transfer* 92 (2016): 893-903. https://doi.org/10.1016/j.ijheatmasstransfer.2015.09.052
[96] Tran, Thanh-Ha, Souad Harmand, Bernard Desmet, and Sebastien Filangi. "Experimental investigation on the feasibility of heat pipe cooling for HEV/EV lithium-ion battery." *Applied Thermal Engineering* 63, no. 2 (2014): 551-558. https://doi.org/10.1016/j.applthermaleng.2013.11.048
[97] Wu, Weixiong, Xiaoqing Yang, Guoqing Zhang, Kai Chen, and Shuangfeng Wang. "Experimental investigation on the thermal performance of heat pipe-assisted phase change material based battery thermal management system." *Energy Conversion and Management* 138 (2017): 486-492. https://doi.org/10.1016/j.enconman.2017.02.022
[98] Wan, Zhenping, Jun Deng, Bin Li, Yanxiao Xu, Xiaowu Wang, and Yong Tang. "Thermal performance of a miniature loop heat pipe using water-copper nanofluid." *Applied Thermal Engineering* 78 (2015): 712-719. https://doi.org/10.1016/j.applthermaleng.2014.11.010
[99] WafirulHadi, Mohamad, Titin Trisnadewi, and Nandy Putra. "Thermal management system based on phase change material (PCM) and heat pipe in Lithium-ion electric vehicle batteries." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 26-35.
[100] Saw, Lip Huat, Hiew Mun Poon, Hui San Thiam, Zuansi Cai, Wen Tong Chong, Nugroho Agung Pambudi, and Yeong Jin King. "Novel thermal management system using mist cooling for lithium-ion battery packs." *Applied Energy* 223 (2018): 146-158. https://doi.org/10.1016/j.apenergy.2018.04.042
[101] Youssef, Rekabra, Md Sazzad Hosen, Jiacheng He, Joris Jaguemont, Lysander De Sutter, Joeri Van Mierlo, and Maitane Berecibar. "Effect analysis on performance enhancement of a novel and environmental evaporative cooling system for lithium-ion battery applications." *Journal of Energy Storage* 37 (2021): 102475. https://doi.org/10.1016/j.est.2021.102475
[102] Wei, Yuyang, and Martin Agelin-Chaab. "Development and experimental analysis of a hybrid cooling concept for electric vehicle battery packs." *Journal of Energy Storage* 25 (2019): 100906. https://doi.org/10.1016/j.est.2019.100906
[103] Zhao, Rui, Jie Liu, Junjie Gu, Long Zhai, and Fai Ma. "Experimental study of a direct evaporative cooling approach

for Li-ion battery thermal management." *International Journal of Energy Research* 44, no. 8 (2020): 6660-6673. https://doi.org/10.1002/er.5402

[104] Ren, Yonghuan, Ziqun Yu, and Guangji Song. "Thermal management of a Li-ion battery pack employing water evaporation." *Journal of Power Sources* 360 (2017): 166-171. https://doi.org/10.1016/j.jpowsour.2017.05.116

[105] Saw, Lip Huat, Hiew Mun Poon, Hui San Thiam, Zuansi Cai, Wen Tong Chong, Nugroho Agung Pambudi, and Yeong Jin King. "Novel thermal management system using mist cooling for lithium-ion battery packs." *Applied Energy* 223 (2018): 146-158. https://doi.org/10.1016/j.apenergy.2018.04.042

[106] Wang, Haimin, Huanqi Li, Zhiyuan Ji, Zhen Yang, Chenglong Jiang, and Hao Lin. "Cooling the electrode tabs with air to manage the heat transferred through the collectors in traction battery." *Journal of Energy Storage* 48 (2022): 103982. https://doi.org/10.1016/j.est.2022.103982

[107] Hunt, Ian A., Yan Zhao, Yatish Patel, and G. J. Offer. "Surface cooling causes accelerated degradation compared to tab cooling for lithium-ion pouch cells." *Journal of The Electrochemical Society* 163, no. 9 (2016): A1846. https://doi.org/10.1149/2.0361609jes

[108] Gocmen, Sinan, and Erdal Cetkin. "Experimental investigation of air cooling with/out tab cooling in cell and module levels for thermal uniformity in battery packs." *ASME Journal of Heat and Mass Transfer* 145, no. 2 (2023): 022903. https://doi.org/10.1115/1.4055939

[109] Waware, Shital Yashwant, Sandeep Sadashiv Kore, and Suhas Prakashrao Patil. "Heat Transfer Enhancement in Tubular Heat Exchanger with Jet Impingement: A Review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 101, no. 2 (2023): 8-25. https://doi.org/10.37934/arfmts.101.2.825

[110] Tejero-González, Ana, and Antonio Franco-Salas. "Optimal operation of evaporative cooling pads: A review." *Renewable and Sustainable Energy Reviews* 151 (2021): 111632. https://doi.org/10.1016/j.rser.2021.111632

[111] Zuckerman, N., and Noam Lior. "Jet impingement heat transfer: physics, correlations, and numerical modeling." *Advances in Heat Transfer* 39 (2006): 565-631. https://doi.org/10.1016/S0065-2717(06)39006-5

[112] Hu, Sihang, Shijie Wang, Chuyuan Ma, Siyang Li, Xiaojie Liu, and Ying Zhang. "A hybrid cooling method with low energy consumption for lithium-ion battery under extreme conditions." *Energy Conversion and Management* 266 (2022): 115831. https://doi.org/10.1016/j.enconman.2022.115831

[113] Yang, Tien-Fu, Pei-Yi Lin, Cong-You Lin, Wei-Mon Yan, and Saman Rashidi. "Study on thermal aspects of lithium-ion battery packs with phase change material and air cooling system." *Case Studies in Thermal Engineering* 53 (2024): 103809. https://doi.org/10.1016/j.csite.2023.103809

[114] Chavan, Santosh, Jie Liu, B. Venkateswarlu, Sang Woo Joo, and Sung Chul Kim. "Numerical simulation of lithium-ion battery thermal management systems: a comparison of fluid flow channels and cooling fluids." *Journal of Energy Storage* 73 (2023): 108940. https://doi.org/10.1016/j.est.2023.108940

[115] Xin, Shiji, Chun Wang, and Huan Xi. "Thermal management scheme and optimization of cylindrical lithium-ion battery pack based on air cooling and liquid cooling." *Applied Thermal Engineering* 224 (2023): 120100. https://doi.org/10.1016/j.applthermaleng.2023.120100

[116] Mahek, Mehwish Khan, Mohammad Alkhedher, Mohammed Ghazal, Mohammad Ali Abdelkareem, Mohamad Ramadan, and Abdul-Ghani Olabi. "Effects of control volume outlet variation on axial air cooling of lithium-ion batteries." *International Journal of Thermofluids* 19 (2023): 100373. https://doi.org/10.1016/j.ijft.2023.100373

[117] Xu, Huanwei, Xin Zhang, Ge Xiang, and Hao Li. "Optimization of liquid cooling and heat dissipation system of lithium-ion battery packs of automobile." *Case Studies in Thermal Engineering* 26 (2021): 101012. https://doi.org/10.1016/j.csite.2021.101012