# Electric Vehicle Battery Systems Thermal Issues

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Electric vehicles battery systems (EVBS) are subject to complex charging/discharging processes that produce various amount of stress and cause significant temperature fluctuations. Due to the variable heat generation regimes, latent heat storage systems that can absorb significant amounts of thermal energy with little temperature variation are an interesting thermal management solution.

Keywords: latent heat storage ; phase change material ; electric vehicle ; battery system ; thermal management ; thermal performance enhancement

## 1. Introduction

The transportation sector contributes a considerable share of total carbon emissions. Approximately 49% of the world oil resources are directed to the transportation sector, Amjad et al. [1]. Efforts to reduce the impact of transportation on climate change has resulted in the rapid development of electric mobility technologies. Electric vehicle requirements in terms of power supply include high voltage, high specific energy, portability, low rate of self-discharge, tolerance to temperature fluctuations, and long operational life, Aneke and Wang [2]. Lithium-ion battery systems satisfy these requirements to the highest degree for plug-in hybrid and pure electric vehicles. However, they have other issues such as sensitivity to temperature, Goutam et al. [3] and vibration, Andwari et al. [4]. The battery thermal management system (BTMS) is a key component of the overall battery system, which must ensure the optimum operating conditions for the battery system. It is also a critical EV system, since its failure can result in irreversible damage of the battery system or even fire. Several review papers report the main technology challenges that need to be resolved. Wang et al. [5] conducted a literature review addressing various battery system models and existing thermal management strategies. Jaguemont and Van Mierlo [6] reviewed traditional BTMS as well as novel hybrid systems, focusing on identifying advantages/disadvantages of each type. Thakur et al. [7] reviewed the current and experimental methods for cooling the EV battery systems. The cooling techniques were analyzed in the context of (1) heat generation governing models and (2) thermal issues emerging from improper thermal management.

Increasing the thermal performance of BTMSs is a matter of utmost concern. Since the EV battery system is a key component and a Single Point of Failure with considerable weight in the vehicle mass, it is critical to ensure the operational conditions specified by the manufacturer in order to obtain the overall performance of the vehicle.

## 2. Battery Systems Thermal Issues

The EV battery generates heat during charging/discharging cycles. The positive electrode generates the highest amount of heat (higher than the rest of the battery components) [7]. With the increase of the temperature, the following irreversible effects occur [8]:

- Chemical reactions between electrolyte and cathode are initiated;
- film forms on the electrode interface;
- decomposition of anode and electrolyte occurs.

### 2.1. Power/Capacity Degradation

Power/capacity loss results in short life cycle, self-discharge, and autonomy losses. No established procedure exists yet to understand and predict the power and capacity losses in batteries due to the usage of various electrode materials.

The most important role in heat generation is the battery electrical internal resistance. The increase in temperature causes the following effects [7]: (1) the dissolution of a carbon-based anode; (2) development of solid electrolyte interface along with active material dissolution; (3) crystal structure becomes volatile; (4) formation of solid electrolyte interface on the cathode material. All these effects lead to an increase of the internal electrical resistance, which in turn accelerates the heat dissipation and temperature increase. Capacity degradation may also occur during storage at elevated temperatures, and surrounding high temperature at high charge state may further increase the power losses. During the first couple of weeks of storage, power losses mainly depend on surrounding temperature, which may cause self-discharging. This type of self-discharging is reversible.

## 2.2. Thermal Runaway

Thermal runaway is caused in general by short-circuit or exothermic reactions during improper charging or discharging. This condition results in generation of a large amount of heat and gases [9] Solid electrolytes which contain metastable components may decompose releasing considerable amounts of heat once the temperature reaches approximately 90 °C [7]. When the electrode of graphite is directly exposed through a partial solid electrolyte interface, then graphite may reach a temperature of 200 °C due to the reaction with the solvent at 100 °C exothermically, but this reaction is prevented from occurring due to the inhibitory effect of LiPF6 salt.

## 2.3. Electrical Imbalance

Electrical imbalance is defined as the capacity difference between various cells of the battery pack. When a cell is charged under electrically unbalanced conditions, the weakest cell is overcharged and significant power loss along with temperature rise occurs [7]. As the cell capacity is significantly influenced by the temperature, the temperature difference in the battery pack can result in electrical imbalance.

## 2.4. BS Behavior at Sub-Zero Temperatures

Li-ion batteries with carbon-based anodes perform poorly at low temperatures due to the following effects:

Reduced conductivity of electrolyte and solid-electrolyte interface, Ratnakumar et al. [10].

Reduced solid-state lithium diffusion rate, Senyshyn et al. [11].

High polarization of the carbon-based anode, Lin et al. [12].

Higher charge-transfer resistance at the electrolyte-electrode interface, Zhang et al. [13].

Zhang et al. [13] reported that the internal battery resistance increased significantly at temperatures below −20 °C. The plating of lithium at the surface of the anode occurs when the battery is charged at extremely low temperatures; the effect is a significant capacity loss, and even internal short-circuits may occur once the lithium dendrites grow and penetrate the battery separator, Waldmann et al. [14]. In the case of a cold start-up after parking the EV for a lengthy period at a low temperature, the performance degradation of Li-ion batteries leads to a significant reduction of the driving range, Hu et al. [15].

## 2.5. Battery Thermal Management Systems (BTMS)

### 2.5.1. General Issues of BTMSs

Thermal management of batteries is a critical component of the EV power supply systems, which not only ensures the normal operation conditions of the battery packs but prevents effects such as thermal runaway, which can irreversibly damage the battery system or can even have fatal consequences.

The BTMSs are categorized in internal management and external management systems. The internal management systems consist of components arrangements that result in less heat generated: selection of the material and thickness of the electrode, increasing the contact surface area between electrodes and electrolyte, etc. The external management systems consist of using latent heat storage, air cooling circuits and multi-phase cooling loops. These systems are complex, expensive and have reliability issues. Moreover, the operation of such systems require energy, which contributes to reducing the EV autonomy.

### 2.5.2. BTMSs Based on Latent Heat Storage

The latent heat storage category of interest for BTMSs consists of Phase Change Materials (PCMs), which absorb/release significant amounts of heat during melting and solidification, respectively, with a relatively small temperature variation. The key properties of PCMs in regulating the temperature are the melting point and the latent heat. The melting point must be close to the set point temperature and the latent heat must be high. The PCMs range of applications is developing continually. A recent review paper, Lawag and Muhammad Ali [16], discusses some new applications of PCMs such as thermal control in data centers and biomedical applications. A detailed classification of PCMs is also provided in [16].

The PCMs applications in vehicles were reviewed by Ugurlu and Gokol [17]. Al-Hallaj and Selman [18] proposed first using PCMs for BTMSs. A recent comprehensive review of BTMSs based on PCMs has been conducted by Zhao et al. [19].

The key condition for a PCM to be suitable in a BTMS application is the melting point value, which must be between the battery system operational limits (from 20 to 50 °C). This condition is met by a relatively wide range of PCMs, both organic and inorganic, such as (1) paraffins, fatty acids, polyethylene glycol and (2) hydrated salts. A comparative analysis of organic and inorganic PCMs from the advantages/disadvantages point of view is presented in **Table 1**. A comprehensive list of commonly used PCMs and their main thermo-physical properties is provided in Agyenmi et al. [20].

**Table 1.** Advantages and disadvantages of organic and inorganic PCMs.

| PCM | Advantages | Disadvantages |
|---|---|---|
| **Organics** | **High latent heat<br>No phase segregation<br>Chemical stability<br>Self-nucleate<br>Extended MP range<br>Compatible with most materials<br>Recyclable<br>Low-vapor pressure** | **Flammable<br>Limited availability<br>Limited biodegradability<br>Significant volume change during phase transition<br>Low thermal conductivity<br>Low volumetric latent heat** |
| **Inorganics** | **Non-flammable<br>High thermal conductivity<br>Phase transition over a very narrow temperature range<br>High volumetric latent heat<br>Low-volume change during phase transition** | **Tendency to undergo supercooling<br>Corrosive<br>May require nucleating and thickening agents<br>Phase segregation** |
| **Eutectics** | **High volumetric latent heat<br>Phase transition over a very narrow temperature range<br>Properties can be modulated to match the application requirements** | **High cost<br>Limited data on thermos-physical properties** |

A key property of the PCMs is the thermal conductivity. The thermal conductivity determines the dynamics of the heat transfer process during the transient regimes of charging and discharging, which translates to effectiveness of the temperature control process. The problem of PCMs thermal conductivity is critical in thermal regulation systems with high rates of heat transfer. Improper choice of the thermal conductivity can result in (1) PCM system inability to limit the temperature increase or (2) failure to fully release the stored heat during the discharge phase and consequently, the system not being ready for the storage phase (this phenomenon is known as saturation).

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