# Battery Thermal Management System for Electric Vehicles: A Brief Review

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**Battery is the heart of an electric vehicle. The global growth of electrification in the automotive market makes improvements in battery health and longevity a vital aspect to consider to accommodate this growing demand. This paper presents a qualitative literature review on different battery thermal management systems (BTMS) for electrified vehicles. Different works in the literature were examined to determine the types of BTMS to be considered and their main characteristics. As a result, we listed different types of BTMS with their main characteristics. This brief review can support the research about battery thermal management systems as a summary of the state-of-the-art on this topic.**
**Keywords: Battery Thermal Management. Battery Cooling. BTMS.**

## Introduction

Lithium-ion batteries have a fundamental role in the acceptance and diffusion of electric vehicles worldwide as they are one of the main components of electric vehicles and, depending on the battery's energy capacity, it can reach 27% of the total cost of the vehicle [1]. Due to this high cost, reducing the degradation and improving the life cycle and safety of lithium-ion batteries are still one of the main challenges for its development and application in electric vehicles [2]. Reviews from the literature showed that the capacity, life cycle, and safety of the battery depend significantly on the temperature, whether it is high (>50 °C) or low (<15 °C) [2-4]. Many temperature ranges are recommended for lithium-ion batteries in the literature, but only a range between 15 °C and 35 °C is desired [5].

Some battery suppliers define four temperature ranges [1-14] as follows: (1) (0–10 °C) decreased battery capacity and pulse performance, (2) (20–30 °C) optimal range, (3) (30–40 °C) faster self-discharge, and (4) (40-60 °C) irreversible reactions, with 60 °C being the upper safety limit under normal operating conditions. Another crucial point is the temperature uniformity between the battery cells in which the temperature difference must be <5 °C [4-8]. Tete and colleagues [4] revealed that at high temperatures, lithium-ion battery cells lost more than 60% of their initial energy after 800 cycles at 50 °C and lost 70% after 500 cycles at 55 °C. In another example, they reported that a lithium-ion battery life cycle at 45 °C is approximately 3323 cycles, and this value is reduced to 1037 cycles at a temperature of 60 °C. Currently, the temperature control of batteries in electric vehicles is done through the use of the battery thermal management system (BTMS).

This system is responsible for ensuring that the battery works in the proper temperature range and keeps the temperature between the cells as homogeneously as possible [1-15].

Based on this context, this paper aims to present a brief literature review on the types and pros & cons of battery thermal management systems for electrified vehicles to drive new researchers on this topic and as a comprehensive data for beginners.

## Materials and Methods

Figure 1 represents the steps and works definition to identify the data used herein.

The first step is the brainstorming session to define the keywords for the initial exploration of battery thermal management system that has as result the following list: "battery cooling", "battery thermal management" and BTMS. The list is intentionally

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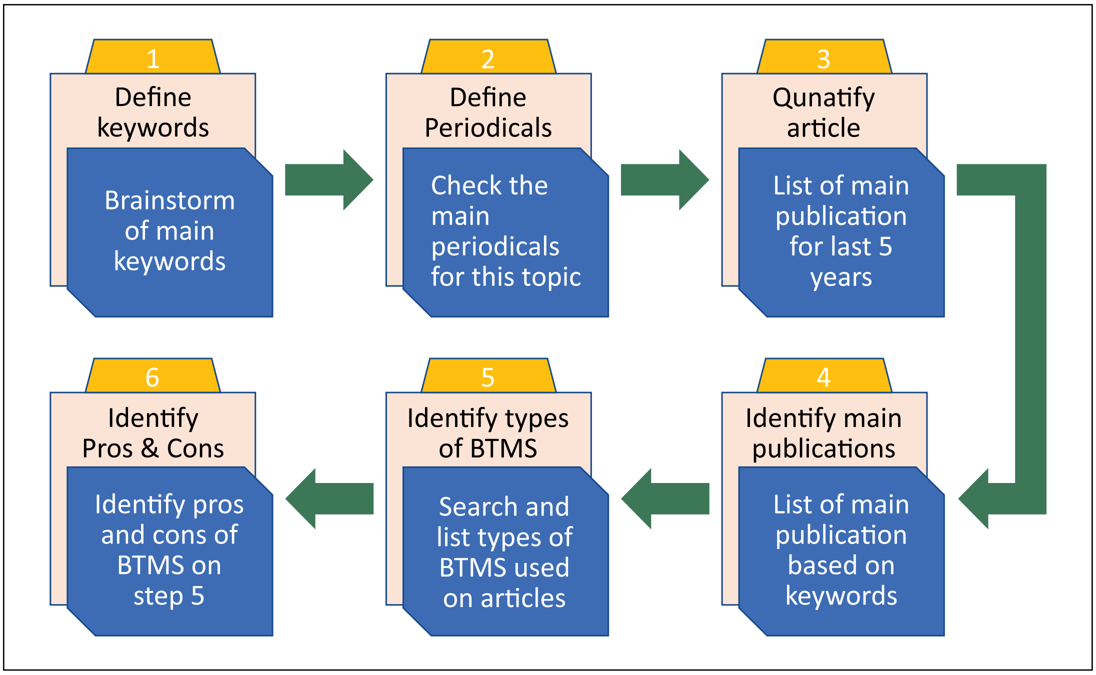
**Figure 1.** Method used in this study on battery thermal management systems for electrified vehicles.

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simple to optimize the number of returned articles on the exploration performed in the scientific periodicals. Those keywords were used on different scientific databases as follows: Science Direct (www.sciencedirect.com), Scopus (www.scopus.com), MDPI (https://www.mdpi.com), Google Scholar (www.scholar.google.com), SAE (www.sae.org/publications/technical-papers), and CAPES Periodicals (www.periodicos.capes.gov.br), as they are the most recognized databases for engineering field. After a few tryouts, it was noticed that there is a large number of articles for each platform, and to simplify the analysis of the publication titles, only review articles published in the Science Direct and MDPI platform were considered due to results aligned with the aim of this paper. These databases are robust scientific directories, which reason why they were considered in these analyses.

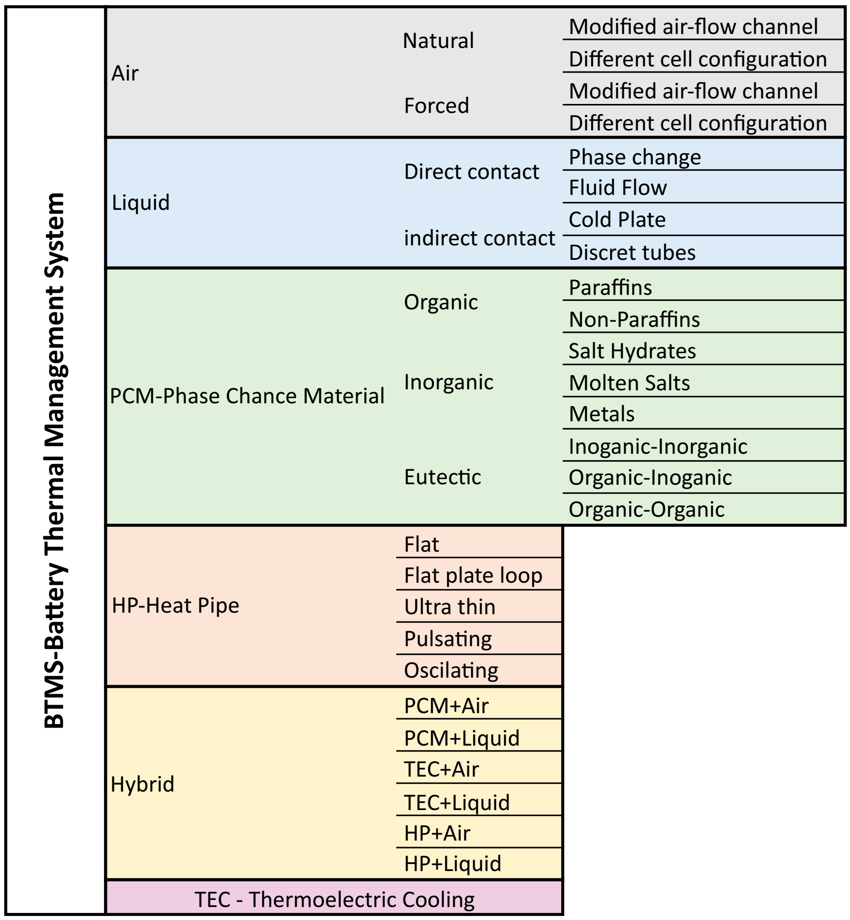
## Results and Discussion

In the literature, there are several forms of BTMS classification. Some authors [4-6] classify it by the system's energy consumption as passive and active, and others [2]classify it by functionality as preheating, cooling, and emergency. The most common form of classification is based on the medium used for heat transfer: air, liquid, PCM-phase change material, TEC-thermoelectric modules, HP-heat pipe, and hybrid models. Figure 2 presents the possibility of grouping the types of BTMSinto 6 main sets - the hybrid set is composed of a combination of two or more types of the other BTMS.

Each BTMS system has a specific feature that makes it more suitable for certain applications. Listed below are the main characteristics to be considered when choosing a medium that will exchange heat with the battery components that need to be cooled or heated [4]:

- Thermal conductivity: It is the capability that the medium has to exchange heat with the environment around it, whereas the higher the coefficient efficiency is, the higher is also the battery temperature control and heat transfer.

**Figure 2.** List of BTMS under study in literature.



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- Heat capacity: the amount of heat to be supplied to an object to produce a unit change in its temperature. The higher the value, the more the medium can accumulate heat with a low-temperature change.
- Viscosity is the resistance a fluid (air or liquid) has to flow. Medium with high viscosities requires more energy to flow. The lower viscosity is the smaller energy consumed by the system.
- Dielectrics: to avoid electrical short, liquids should be as deionized water, silicon-based oils, or mineral oils.
- Nontoxic: It can't cause damage to the operator or environment.
- Inflammable: In case of leakage, it can't catch fire when exposed to a hot surface.
- Good chemical stability: It can't change properties or composition in long-term usage.

Despite the characteristics of the medium, the BTMS system must have some fundamental characteristics, such as follow: cooling to remove heat from the battery, heating for very low-temperature environments, insulation to prevent sudden changes in battery temperature, ventilation to exhaust the potentially dangerous gases from the battery, as has a low volume as space in vehicles are limited, be light helps the system's efficiency, low cost, high reliability since the battery is the heart of the electric vehicle, low energy consumption (pump, fans, and heaters), easy maintenance and assembly.

Currently, each OEM has its particularity in the definition of the thermal management system, but, for hybrid and electric vehicles with low power batteries, the most adopted cooling system is air due to its simplicity and low energy consumption. On the other hand, in hybrid vehicles and 100% electric vehicles with high battery power demand, the most widespread system is liquid cooling due to the ability to keep the battery at the ideal temperature even in extreme battery usage and high heat release. In a comparative assessment carried out by Han and colleagues [15], they demonstrated that while the liquid cooling system has a rating of 500 W/K, the air-cooling system is around 70 W/K. Table 1 shows the main characteristics of each BTMS.

## Conclusion

This paper highlights the importance of BTMS for electrified vehicles and reveals the current BTMS under study in the literature and their pros and cons. Despite the many varieties of BTMS in the literature and their pros and cons, only air and liquid cooling have been implemented for commercial purposes in electric vehicles and hybrid electric vehicles, whereas other cooling methods are still under research. It indicates a long way to run research and development technics that make the most efficient BTMS feasible to implement and commercialize.

These findings are significant to support new research on this topic and can be used as comprehensive information for beginners on electrified vehicles, giving directions on types of battery cooling and critical points during definition and usage.

**Table 1.** BTMS pros and cons.

| BTMS | Pros | Cons |
|---|---|---|
| **Air** | Simplicity, low weight, electrical safety, easier maintenance, no worries about leaks, and low cost [4-8,15]. | Low thermal conductivity, and wind noise, can't be used for high cooling demand [4-8,15]. |
| **Liquid** | High thermal conductivity, is mostly applied for high cooling demand [2-15]. | Complexity, high cost, heavy, must store the fluid, viscosity, potential leaks, additives for anti-freeze & Boiling [2-15]. |
| **PCM** | Passive BTMS, better thermal management due to its high latent heat, promises effective thermal energy storage [2-13]. | Low thermal conductivity, need an additive to improve thermal conductivity, can't be used alone just works with hybrid model [2-13]. |
| **HP** | Passive BTMS, good thermal conductivity [4]. | Can't be used alone just works with the hybrid model, low efficiency, and small contact area [4]. |
| **TEC** | Using the Peltier effect can heat and cool at the same surface depending on the current direction, and low complexity [4,6,14]. | Low thermal conductivity, can't be used alone just works with a hybrid model [4,6,14]. |
| **Hybrid** | It has the pros of each method that it decides to combine [6]. | It has the cons of each method that it decides to combine [6]. |

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