BATTERY THERMAL MANAGEMENT SYSTEM FOR ELECTRIC VEHICLES: A BRIEF REVIEW

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Abstract: Battery is the heart of an electric vehicle and the global growth of electrification in the automotive market, makes improvements in the battery health and longevity an important aspect to consider, in order to accommodate this growing demand. This paper aims to present a qualitative review of the literature on different types of battery thermal management system (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, a set of different types of BTMS with their mains characteristics were listed. In conclusion, this brief review can support the researches about battery thermal management system as a summary on the state of the art on this topic.

Keywords: Battery Thermal management, Battery cooling, BTMS.

SISTEMA DE GERENCIAMENTO TÉRMICO DE BATERIAS PARA VEÍCULOS ELETRIFICADOS: UMA BREVE REVISÃO

Resumo: A bateria é o coração de um veículo elétrico e o crescimento global da eletrificação no mercado automotivo torna as melhorias na saúde e na longevidade da bateria um aspecto importante a ser considerado, a fim de acomodar essa demanda crescente. Este artigo tem como objetivo apresentar uma revisão qualitativa da literatura sobre diferentes tipos de sistemas de gerenciamento térmico de baterias (BTMS) para veículos eletrificados. Diferentes trabalhos da literatura foram examinados para determinar os tipos de BTMS a serem considerados e suas principais características. Como resultado, um conjunto de diferentes tipos de BTMS com suas características principais foram listados. Como conclusão, esta breve revisão pode subsidiar as pesquisas sobre sistemas de gerenciamento térmico de baterias como um resumo do estado da arte neste tópico.

Palavras-chave: Gerenciamento térmico de bateria, Resfriamento de bateria, BTMS.

1. 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 [1,12]. Due this high cost, to reduce the degradation and to improve 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 [2-4], [3] and [4] show 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). Many temperature ranges recommended for the use of lithium ion batteries are found 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]: (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 important point is the temperature uniformity between the battery cells in which the temperature difference must be less than 5 °C [4-8].Tete et al. [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 the life cycle of a lithium-ion battery at 45 °C is approximately 3323 cycles, and that 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 types and pros & cons of battery thermal management system for electrified vehicles in order to drive new researchers on this topic and as a comprehensive data for beginners.

2. METHODOLOGY

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

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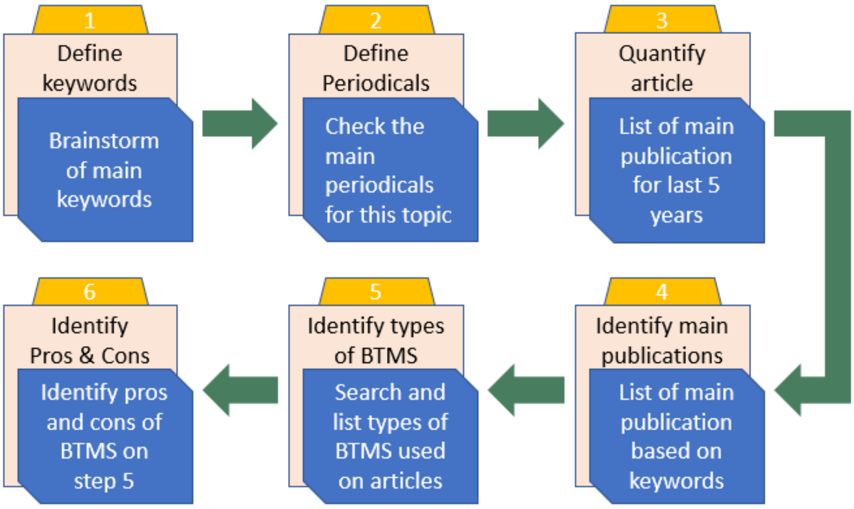
Figure 1: Methodology used on the search of papers on battery thermal management systems for electrified vehicles.



Source: elaborated by the authors.

The first step is the brainstorming session to define the keywords for the initial exploration on battery thermal management system that has as result the following list: "battery cooling", "battery thermal management" and BTMS. The list is intentionally simple and short to optimize the number of returned articles on the exploration performed in the scientific periodicals. Those keywords ware 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 try outs, it was noticed that there is a huge number of articles for each platform, and to simplify the analysis on 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, reason why they were considered in these analyses.

3. 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. As can be seen in Figure 2, it is currently possible to group the types of BTMS into 6 main sets, the hybrid set is composed of a combination of two or more types of the other BTMS.

Figure 2: List of BTMS under study in literature.

BTMS-Battery Thermal Management System		
Air	Natural	Modified air-flow channel
		Different cell configuration
	Forced	Modified air-flow channel
		Different cell configuration
Liquid	Direct contact	Phase change
		Fluid Flow
	indirect contact	Cold Plate
		Discret tubes
PCM-Phase Chance Material	Organic	Paraffins
		Non-Paraffins
	Inorganic	Salt Hydrates
		Molten Salts
		Metals
	Eutectic	Inoganic-Inorganic
		Organic-Inoganic
		Organic-Organic
HP-Heat Pipe	Flat	
	Flat plate loop	
	Ultra thin	
	Pulsating	
	Oscilating	
Hybrid	PCM+Air	
	PCM+Liquid	
	TEC+Air	
	TEC+Liquid	
	HP+Air	
	HP+Liquid	
TEC - Thermoelectric Cooling		

Source: elaborated by the article authors.

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, the higher the coefficient efficiency is, the higher is also the battery temperature control and heat transfer.
- **Heat capacity:** the amount of heat to be supplied to an object to produce a unit change in its temperature. The higher the value, more the medium is able to accumulate heat with small change in temperature.
- **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, less energy will be consumed by the system.
- **Dielectrics:** to avoid electrical short, liquids should be as deionized water, silicon-based oils, or mineral oils.
- **Nontoxic:** Can’t cause damage to the operator or environment.
- **Inflammable:** In case of leakage, it can’t catch fire when exposed to 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 as a whole must have some fundamental characteristics such as: 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 in general, for hybrid and electric vehicles with low power battery, 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 situations of extreme battery usage and high heat release. In a comparative assessment carried out by Han et al. [15], it was 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 mains characteristics for each BTMS.

Table 1: BTMS Pros and Cons.

BTMS	Pros	Cons
Air	simplicity, low weight, electrical safety, easier maintenance, no worries about leaks, low cost [4-8,15].	low thermal conductivity, wind noise, can't be used for high cooling demand [4-8,15].
Liquid	High thermal conductivity, 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 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 hybrid model, low efficiency, and small contact area [4].
TEC	Use the Peltier effect, can heat and cooling at same surface depending on current direction, low complexity [4,6,14].	Low thermal conductivity, can't be used alone just works with 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].

Source: elaborated by the article authors.

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4. 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. This indicates that there is a long way to run research & development technics that makes the most efficient BTMS to be feasible to implemented and commercialize.

These findings are significant to support new researches 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.

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