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Review article

A comprehensive review on a passive (phase change materials) and an active (thermoelectric cooler) battery thermal management system and their limitations

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HIGHLIGHTS

- A comprehensive survey of PCM and TEC based BTMS has been presented.
- This paper will help to develop a new configuration of BTMS in future.
- This paper will help to identify the application fields of different PCM based BTMS.
- This review provides a list of limitations which will help to do further research.
- This paper will allow developing hybrid BTMS.

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ABSTRACT

A battery thermal management system (BTMS) has become an essential part in battery-driven electric vehicles (EVs) in order to remove the generated heat from the battery which leads to enhanced performance. BTMSs have been implemented in EVs by adopting different technologies that include natural air cooling systems, forced air cooling systems, liquid cooling systems, and using heat pipes and fins. However, phase change material (PCM) embedded systems have gained a lot of attention due to their availability, low cost, and high sensible and latent heat in the field of BTMS. In the last two decades, thermoelectric coolers (TECs) have also been applied to BTMSs to make an active or semi-passive system with another cooling system. In this paper, a state of the science comprehensive literature review is presented on PCM (a passive system) and TEC (an active system) based BTMSs. A synthesis of the literature is presented in a tabular format to give a clear indication on the relative performances of the BTMSs. Moreover, limitations of the batteries, PCMs, and TECs are also discussed to identify the future research possibilities in the area of BTMS for EVs.

1. Introduction

Over the last decade, electric vehicles (EVs) have rapidly become a technological focus to offset fossil fuel consumption and limit the negative environmental impacts of vehicular traffic that include ground level ozone, regional smog, and climate change [1]. By replacing fossil fuel vehicles with EVs powered by batteries, many of the adverse environmental effects can be avoided. EVs thus represent a huge and growing market as they have become a reliable means of transportation due to their low operating costs, rapid acceleration, high speeds, and their long-lasting and efficient battery technology [1]. However, compared to internal combustion vehicles, EVs have some major issues such as their overall weight, limited driving range, high initial purchase cost, battery life cycle, and the thermal management of the batteries [2].

To increase public acceptance of EVs, the key will be to reduce the negative issues that surround the batteries that power the EVs. The battery is an electrical device that combines two or more cells where electrochemical reactions take place to supply power to any electrical device. Typical rechargeable chemical batteries include lead, sodium, alkaline, and lithium batteries [1,3]. For EVs, however, nickel metal hydride (Ni-MH) batteries and lithium ion (Li-ion) batteries are most commonly installed in third generation electric vehicles due to the requirements of high energy densities, high power outputs, and longer lifetimes [4]. These EV batteries, however, face huge temperature rises during charging and discharging periods with the non-uniform temperature distribution in the battery resulting in reduced battery

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Nomenclature

BEV	Battery electric vehicle
BTMS	Battery thermal management system
CENG	Compressed expanded natural graphite
CFD	Computational fluid dynamics
COP	Coefficient of performance
EG	Expanded/enhanced graphite
EV	Electric vehicle
FE	Finite-element
HEV	Hybrid electric vehicle
ISG	Integrated starter generator
MWCNT	Multi-walled carbon nanotubes
NS	Nano-silica
OHP	Oscillating heat pipe
PCC	Phase change composite
PCM	Phase change material
PHEV	Plug-in hybrid electric vehicle
PPI	Pores per Inch
TEC	Thermoelectric cooler
TMS	Thermal management system

performance and overall efficiency of the vehicles [5].

In light of this reduced performance, a battery thermal management system (BTMS) has become very important for EVs in order to manage the generated heat and the temperature distribution within the cells. Various thermal management systems (TMS) that are commonly used for batteries include: natural air cooling systems, forced air cooled systems, liquid cooling systems, heat pipe assisted cooling systems, phase change material (PCM) embedded cooling systems, and thermoelectric cooler (TEC) based systems [6].

In this article, a state of the science comprehensive literature review and synthesis is presented on the use of PCM and TEC cooling systems for managing thermal profiles in batteries as these represent some of the most promising results for BTMSs of EVs. Discussion of PCM embedded BTMS is based on two main subsections based on the battery geometry (cylindrical shaped and rectangular shaped batteries). Moreover, active thermoelectric cooler based BTMSs are discussed. At the end, some major limitations of battery technology, PCMs, and TECs are discussed in terms of future research possibilities.

2. Electric vehicles

Electric vehicles (EVs) have become a key asset as an alternative to traditional fossil fuel vehicles to combat climate change and to ensure a more overall environmentally friendly transportation sector [7]. The first EV was introduced in the mid-19th century [8]. However, while commercial uptake of EVs has been slow, the recent popularity of EVs is rising relative to internal combustion vehicles due to their cheap energy costs and market incentives for electric cars [9]. To offset the initial slow market uptake of pure EVs (i.e. no additional energy source other than the battery), many car manufacturers introduced hybrid EVs (HEVs) that combine an internal combustion engine with an electric motor and battery. In addition, plug-in HEVs (PHEVs), which require an additional plug to be charged using an external source, have also been introduced into the market. The demand for EVs and HEVs is expanding rapidly due to the technological advancement in batteries and electronic motors. A prospective survey on increasing demand of EVs, HEVs, gasoline vehicles, and fuel-cell vehicles is shown in Fig. 1 which shows an increase in EV growth from 15 to 30% of total vehicles from 2020 to 2030 [9,10].

Characteristics of the different EVs are provided in Table 1. Rapid growth in commercial EV production, such as the BMW i3, the Nissan Leaf, and the Tesla Model S, is primarily due to the development of more efficient Li-ion batteries which power the motor and thus drives the vehicle. The battery is the key operating tool to drive the EV and the performance of the EV actually depends on the performance of the battery (i.e. the capacity of the battery, operating period, discharge rate, and power density). Moreover, the battery is the key barrier to making EVs commercially attainable in terms of cost. One of the biggest issues with the battery is that it generates heat during the charge and discharge period [11–21], requiring a thermal management system (TMS), especially for Li-ion batteries.

3. Battery thermal management system

The rated operating temperature of an EV battery varies for different battery types from −40 °C to 60 °C (see Table 2) [24]. However, it is noted that the desired operating temperature for EV is between 15 °C and 35 °C in order to get optimum output from the battery [22,24,25]. If the temperature goes beyond 35 °C or below 15 °C then the battery needs to be thermally managed to maintain the temperature within the operating range but also to keep the temperature below the safety limit of the Li-ion cell which is 60 °C [22]. To do this, a battery thermal management system (BTMS) that monitors, controls, and manages the battery's performance and the ensuing thermal behavior is employed [26]. BTMSs try to keep the battery system within the rated operating temperature range to get the optimum work done by the battery.

The key features of any BTMS include: ease of installation, small in size and rigid, inexpensive, low weight, easy to operate and maintain, reliable, and no harmful gases emission [27]. BTMSs can be divided into two main categories, namely passive and active systems. A suitable description with a graphical illustration of a BTMS is presented in Fig. 2. Table 3 illustrates the advantages and disadvantages of passive and active battery thermal management systems.

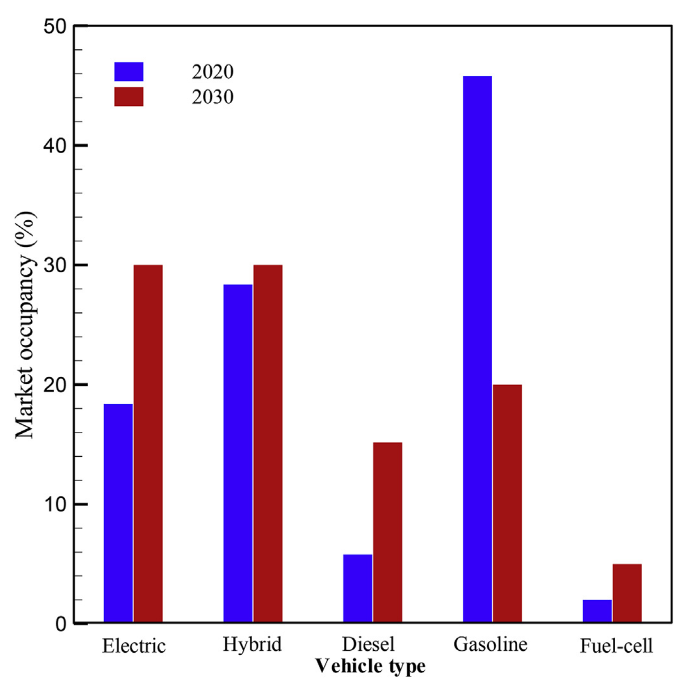

Fig. 1. Perspective survey on the global demand of EVs between 2020 and 2030 [9,10].