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A LITERATURE SURVEY ON CFD ANALYSIS OF BATTERY THERMAL MANAGEMENT SYSTEM

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Abstract

The BTMS plays a pivotal role in maintaining the operating temperatures of individual cells within acceptable limits, thereby preventing thermal runaway, degradation, and potential safety hazards. CFD analysis provides a virtual platform to investigate and optimize the intricate heat transfer processes occurring within the battery pack. By leveraging numerical simulations, engineers gain insights into temperature distributions, flow patterns, and thermal gradients, facilitating the refinement of BTMS designs. This study embarks on a detailed exploration of CFD analysis applied to Battery Thermal Management Systems, aiming to unravel the intricacies of heat transfer mechanisms, fluid dynamics, and thermal regulation within these critical energy storage components. Through a systematic investigation, we seek to identify optimal cooling strategies, assess the impact of varying operating conditions, and propose design modifications that enhance the overall performance and reliability of battery systems.

Keywords: CFD, Thermal,BatteryManagement.

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1. INTRODUCTION

The continuous evolution of electric vehicles, portable electronic devices, and renewable energy storage solutions has propelled the demand for high-performance batteries. Ensuring the optimal thermal management of these batteries is paramount to enhance their safety, efficiency, and longevity. The intricate interplay between electrochemical reactions, heat generation, and heat dissipation within battery systems necessitates a comprehensive understanding of thermal dynamics. Computational Fluid Dynamics (CFD) emerges as a pivotal tool in this pursuit, offering a sophisticated means to simulate and analyze the complex thermal behaviours of Battery Thermal Management Systems (BTMS). A Battery Thermal Management System (BTMS) is a crucial component in energy storage systems, especially in applications such as electric vehicles (EVs), portable electronic devices, and grid-scale energy storage. The primary purpose of a BTMS is to regulate and control the temperature of the battery pack to ensure optimal performance, safety, and longevity of the batteries. Batteries are sensitive to temperature changes, and their efficiency and lifespan can be significantly affected by extreme temperatures. A well-designed BTMS helps maintain the battery cells within an optimal temperature range by managing heat generated during charging and discharging cycles.

- **Cooling Systems:** Various cooling methods may be employed, such as liquid cooling or air cooling, to dissipate excess heat from the battery cells. Liquid cooling systems often use a coolant circulating through channels or pipes within the battery pack.
- **Heating Systems:** In cold climates, BTMS includes heating elements to prevent the batteries from getting too cold, which can negatively impact their performance and efficiency.
- **Thermal Insulation:** Insulation materials are used to minimize heat loss or gain, ensuring that the battery operates within the desired temperature range.
- **Thermal Sensors:** Temperature sensors are strategically placed within the battery pack to monitor and provide real-time feedback to the BTMS. This allows for precise control and adjustment of the thermal management system based on the current operating conditions.
- **Control System:** A sophisticated control system manages the overall operation of the BTMS, adjusting the cooling or heating elements based on the data from thermal sensors and optimizing the thermal conditions for the batteries.
- **Safety Features:** BTMS often incorporates safety mechanisms to prevent overheating, thermal runaway, or other potentially hazardous conditions. These features may include emergency cooling measures or shutting down the battery system in extreme cases

2. LITERATURE REVIEW

Dinçer et al., (2017), rising pollution levels, climate change and global warming are the pressing issues which have made the requirement of alternate energy source utilization imperative. The transition to electric vehicles is the current focus as far as the automotive industry's contribution is concerned.

Batteries are the most feasible amongst the various alternative energy storage systems, owing to their efficient peak and average power delivery rates [1]. Pesaran et al., (2013), out of the several existing battery technologies, the Lithium-ion battery technology is primarily used because of its high specific power, energy density, longer life cycle, reduced weight, and absence of memory effect. However, the thermal sensitivity of these batteries, significantly impacts their overall performance and durability. The operating conditions are limited to a narrow temperature range of 15°C and 35°C for optimum operation of Lithium-ion battery systems, and the temperature variation should not exceed 5°C for a multi-cell module [2]. Bandhauer et al., (2011) there are several aspects of battery's safety which can lead to further degradation in battery life and performance such as suboptimal performance due to sluggish chemistry during low temperature battery operation, the ambient temperatures causing the battery to exceed the upper temperature limit coupled with capacity fade, and electrical imbalance and/or self-discharge [3]. Wang et al., (2012) Temperature uniformity is desirable to prevent thermal runaway and associated implications. Therefore, an appropriate thermal management for the battery systems is required [4]. Wang et al. (2016) emphasis on the requirement of an effective Battery Thermal Management System (BTMS) to enhance the electric vehicle performance, which necessitates increasing the number of cells and energy density, results in rise of the battery temperature. An efficient BTMS is essential to avoid degradation of the battery overtime and maintenance of optimal performance capability. In this study, development of a cooling system for the battery is emphasized for acknowledging the adverse effects of exceedingly high temperature in the battery and with regards to safety [5]. Rao and Wang (2011) BTMS is tasked with maintaining the appropriate temperature range by removing heat from the battery at higher temperatures, adding heat during low temperature conditions and insulation to maintain uniformity of temperature distribution in a battery module [6]. Kim et al., (2018) Several approaches have been utilized to accomplish the mentioned tasks resulting in the classification of BTMSs according to their medium of cooling (air, liquid, or solid PCM) thermal cycle (with or without vapor compression cycle) [7]. Sabbah et al., (2008) As a result of comparison between active (forced air cooling) and phase change material (PCM) based passive cooling BTMS, it is observed that PCM based system is more efficient as compared to the active fan cooling system at high ambient temperatures and discharge rates [8]. Ling et al., (2015) argue that for the continuous operation of the BTMS, PCM alone is not sufficient due to the complete phase change at higher temperature. Vapor compression cooling is an easy to construct and proven conventional technology. It struggles with inadequate overall performance due to the single-phase cooling using a low thermal conductivity fluid (water) and several heat exchangers, results increasing its size, weight, power requirement and cost [9]. Jin et al., (2014) have proposed a liquid cold plate design for thermal management which highlights its compactness, effectiveness, and ease of implementation. The indirect liquid cooling system is better in comparison to air cooling systems for handling high heat dissipation rates in EV batteries [10]. Koyama et al., (2019) The liquid cooling BTMS have a better cooling efficiency and capacity, and lesser noise generation, but these are bulky and consume more energy [11]. Westbrook and Westbrook (2001) air cooling BTMS are comparatively light, cheap, and reliable with a simpler and compact design [12]. Wang et al., (2014) This has encouraged their adoption in Nissan Leaf, Honda Insight, Lexus and Toyota Prius despite their shortcomings which include increased energy requirement and noise. Improvisation in the air cooling BTMS design can help augment the overall performance of the automobile [13]. Kang et al., (2020) the design optimization of air cooling BTMS could be accomplished by different arrangements such as modifying the packing arrangement in Parallel, staggered, cross, dense, line, rectangular, square, hexagonal and ringed arrangements [14]. Yang et al., (2015) conducted on a single cell of the battery pack with forced-air cooling system. The effects of longitudinal and transverse spacing on the cooling performances are analyzed for the battery pack with the aligned and the staggered arrays. Under a specified flow rate of cooling air, the maximum temperature rise is proportional to the longitudinal interval for the staggered arrays, while it is in inverse for the aligned arrangement [15]. Fan et al., (2019) comprehensively investigate the characteristics of an air-cooling system, a battery pack with 32 high energy density cylindrical lithium-ion batteries is designed in this paper. Using a series of evaluation parameters, the air-cooling performances of aligned, staggered, and cross battery packs are experimentally studied and compared at different air inlet velocities [16]. Yu et al., (2019) studied a stagger-arranged battery pack consisting of three battery modules was developed to explore its transient thermal characteristics in charging/discharging process under the two cooling strategies, i.e., natural cooling and forced air cooling. The investigation of heat generation behavior of the battery with Li (NixCoyAlz)O2 cathode showed that the heat generation rate of the battery remains almost unchanged along the main discharging process, while a rapid increase in heat production is detected at the end of discharging [17].

Lu et al., (2016) modifying the air flow channel as tilting the case by 5^o to reduce the air flow drag, arranging the batteries horizontally, using two-sided cooling with wide unequally spaced channel, employing reciprocating airflow channel, directing the airflow via thin ducts, baffles, inlet plenum, novel U-Type channel, Z-Type channel and J-Type channels [18]. Ye et al., (2018) simulation results are compared with the experimental results to verify the validity of the model. By the Ansys Workbench software, the three-dimensional model is established based on the conjugate thermal transfer phenomenon. Based on the fluid-solid conjugate heat transfer mechanism, the influence of the airflow channel spacing and air inlet angle on the temperature distribution of the battery pack is analyzed, thus optimizing the heat dissipation structure. By studying the effect of the air flow rate and its temperature on the temperature distribution of the battery pack, the optimized heat dissipation structure can achieve the best performance [19].

Xu et al., (2013) the heat dissipation performance of bottom duct mode is more superior; for battery pack with bottom duct mode, it uses the double "U" type duct instead of double "1" type duct in order to improve the heat dissipation performance; when the heat dissipation condition is poor, it could reduce the SOC state or charge & discharge rate to satisfy the heat dissipation performance requirements; as considering the practical operation condition of battery pack with double "U" type duct, it has a large margin of high charge and discharge rate to meet the needs of electric vehicle acceleration or deceleration operation [20]. Shahid et al., (2017) Other innovative and effective modifications include incorporation of vortex generators, tapering of manifold and provision of holes for pressure relief and creating a negative pressure gradient in the pack [21]. Zhao et al. (2021) have reviewed the air cooling BTMSs and concluded that increasing convective heat transfer and turbulence by incorporation of fins and winglets enhances temperature uniformity [22]. Wang et al., (2021) have used parallel plates to change the airflow inside the battery back and analysed the effect of number and location of plates on cooling performance. They observed that as the number of plates is increased from 0-9, the value of maximum temperature difference first decreases, then increases and then again decreases. Moreover, more the number of plates more is the power dissipation [23]. Shahid et al., (2021) proposed innovative hybrid and passive techniques for thermal management as using delta shaped vortex generators in incoming airflow to develop turbulent and omitting dead air regions by redirecting flow using jet inlets. The hybrid battery pack design resulted in about 89% increase in temperature uniformity and 74% reduction in temperature variance. The authors observed that altering the air flow pattern seems to be an efficient method to avoid uneven airflow distribution and for improving the battery pack cooling efficiency. Also, combination of different types of BTMS has been observed to render enhanced performance results [24]. Chen et al., (2005) compared different modelling strategies to identify the simplified model with optimum efficiency and accuracy, and to assess the thermal behavior of the Li-ion battery. The authors proposed a model to concurrently study the effect of radiation and convection which is 660 times faster and possess an accuracy near to that of a detailed model. Moreover, they inferred that enhancement of forced convection though leads to a decrease in the maximum temperature but decreases the temperature uniformity [25].

3. CONCLUSION

The literature review provides a comprehensive synthesis of the current state of research in the CFD analysis of Battery Thermal Management Systems. The reviewed studies collectively contribute to a nuanced understanding of thermal dynamics within batteries, offering insights into effective strategies for heat dissipation and system optimization. This body of knowledge not only reflects the advancements made but also highlights avenues for future research, guiding the ongoing efforts to enhance the safety and efficiency of battery systems across diverse applications.

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