

ABSTRACT

In recent years, a shift from internal combustion engines to electric vehicles has been intensified due to increasing global environmental concerns. The lithium-ion battery is key to this transformation because of its several benefits, such as specific power output, higher energy density, and longer life span. However, the major concern is that its performance is highly sensitive to working temperatures, especially under dynamic driving conditions. Battery Thermal Management Systems (BTMS) are therefore essential in electric vehicle design to alleviate any thermal issues in the battery pack and maintain its consistent performance. BTMS has been classified into various categories based on the cooling medium utilized, namely Air Cooling, Liquid Cooling, Phase Change Material-based Cooling, etc. Furthermore, BTMS are typically classified as active and passive cooling systems. Active cooling systems necessitate an external energy source, specifically the energy necessary to operate fans or pumps in air or liquid cooling systems. Passive cooling solutions require no external energy sources, such as PCM or a heat pipe-based cooling system. Among the various cooling strategies available, liquid cooling-based BTMS are recognized for their exceptionally good heat transfer capabilities and compact configurations.

This thesis presents a comprehensive performance analysis of liquid cooling-based BTMS in electric vehicles through both numerical and experimental studies. A cold plate liquid cooling-based BTMS has been proposed, and its performance with water as a coolant has been analysed at different ambient temperatures for actual driving cycles. The present study employs a MATLAB/Simulink model for a liquid cooling-based BTMS in an electric vehicle. The battery pack is positioned above the cold plate. The coolant circulates in the cooling channels integrated within the cold plate. The liquid coolant extracts heat from the battery pack, and the study examines changes in the average battery pack temperature along with the total energy consumed by the BTMS. The simulation model is designed to maintain the battery pack at a constant temperature of 25°C. Additionally, the influence of varying ambient temperatures on the efficacy of the liquid cooling system has been examined. Findings indicate

that as the ambient temperature increases, the BTMS requires more time duration to lower the battery pack temperature, and overall energy usage also rises. The following chapter extends this analysis by evaluating the BTMS performance using three different coolants. To identify the most effective coolant and its ideal concentration, mixtures of water with ethylene glycol and propylene glycol at various ratios are tested. These additives are blended with water to enhance the coolant's thermal characteristics. In the case of a Water-Propylene glycol mixture, 25% propylene glycol concentration is advised; however, for a water-ethylene glycol mixture, 50% ethylene glycol concentration provides the optimal results.

Furthermore, in addition to BTMS in EVs, this thesis also focuses on the vehicle cabin thermal management. An integrated thermal management system, combining a BTMS with a vehicle cabin air conditioning system, is a viable approach to improving energy efficiency and reducing space requirements in electric vehicles. This study investigated the efficacy of an integrated system for EVs under an actual driving cycle. The simulations are conducted in MATLAB/Simulink, and the performance is analyzed at ambient temperatures and relative humidity levels. The model has been formulated in such a way as to regulate the cabin temperature between 22–24°C and the battery pack temperature within a safe range of 30–35°C. The results indicate that as ambient temperature rises, the duration required for the integrated system to attain the set cabin temperature increases, owing to increased heat exchange between the vehicle cabin and the surrounding environment at higher ambient temperatures. At 25°C ambient temperature, the cabin air conditioning system requires 625 seconds to reach the required set point cabin temperature, whereas at 30°C and 35°C ambient temperature, the corresponding time durations are 2045 seconds and 2150 seconds. The BTMS, being more vital, gives an optimal performance and maintains the battery pack temperature in the range of 30–35 °C at different ambient conditions.

Finally, an experimental study has been carried out to analyse the efficacy of the immersion cooling technique for lithium-ion battery packs. Indirect liquid cooling systems, such as those utilizing a cold

plate, have shown effective performance by maintaining the battery pack temperature within the specified range. With the increasing demand for fast charging in EVs, immersion cooling techniques for LiB are gaining popularity. Immersion cooling has superior heat transfer efficiency as it maintains direct contact between the coolant and the battery surfaces, eliminating the thermal resistance introduced by intermediate materials like a cold plate, etc. Also, the battery packs are submerged in coolant, directly ensuring even temperature distribution in the cells. This research seeks to assess cooling efficiency, thermal uniformity, and the effects of immersion cooling technique on lithium-ion battery performance. In this study, the battery pack is made using 9 cells in a 3x3 arrangement (3S3P), i.e., three cells in a row, each connected in a series, and each row is connected in a parallel connection. The study offers an in-depth analysis of the thermal characteristics of LiB cells submerged in transformer oil through the integration of thermocouples, data loggers, climate chambers, and a power supply. The results demonstrate a substantial reduction in the maximum temperature of the centre cell when the battery pack is entirely immersed in the transformer oil. The transformer oil has a greater specific heat than air, and immersion cooling also has a higher heat transfer coefficient. Therefore, the complete immersion of the battery pack in the transformer oil enables more heat dissipation from the batteries.

In summary, this thesis delivers a detailed exploration of liquid and immersion cooling-based BTMS for EVs, using both simulation and experimental approaches. Furthermore, the integration of BTMS with cabin thermal management is shown to improve energy efficiency and system compactness, a crucial step toward optimizing EV design. The immersion cooling study, in particular, underscores the superior thermal regulation, making it a promising solution for high-demand applications like fast charging. Overall, the research contributes valuable knowledge toward developing robust, energy-efficient, and safe BTMS strategies for next-generation EVs.

Keywords: Lithium-ion battery; Immersion Cooling; Integrated thermal management system;
Liquid cooling, Electric Vehicles