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Hybrid EV Battery System Thermal Management Designing Lab-Scale Battery Performance Testing Systems

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ABSTRACT

Thermal management plays a crucial role for HEV and EV battery systems to maintain their performance, durability and safety of the battery system. As lithium-ion batteries are widely incorporated in these systems, the thermal management of heat produced during their operation has been challenging. This paper discusses the aspects of lab-scale battery performance testing systems with specific attention paid to the incorporation of advanced cooling systems. It compares liquid cooling with phase change materials (PCMs) with passive and active hybrids with their strengths and weaknesses in heat dissipation and impact on battery degradation and cost. Other parameters of performance that are assessed in the course of the study include temperature profile, thermal conduction and reaction time of the system. Last of all, the paper lays out the prospects of battery thermal management research, the use of new types of composite materials, effectiveness of new designs on different levels of battery scaling, as well as smart control and monitoring of real-time thermal activity.

INTRODUCTION

With ever increasing demand for sustainable modes of transport, the contribution of Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs) towards emissions of greenhouse gases has become even more crucial. One of the most crucial parts of this kind of cars is the energy storage system, to be precise – lithium-ion (Li-ion) batteries that are used to drive electric motors. Nevertheless, controlling the thermal performance of these battery systems constitutes one of the toughest challenges to efficiency, reliability as well as safety of HEVs and EVs.

Li-ion batteries produce heat during charging and discharging due to high capacity requirements during energy-conversion processes in high-performance or extended-travel driving cycles. Excessive heat can cause batteries to be overcharged or discharged, decrease capacity and sometimes create safety issues like thermal runaway. Thus, the thermal management system (TMS) plays a crucial role in achieving and maintaining battery cells working temperature in the range that would prevent the occurrences of critical failures.

In analysing the current lab-scale battery performance testing systems for the purpose of thermal management, this paper aims at proposing the best techniques to approach. This paper overviews current techniques and technologies used in cooling HEV and EV battery systems, identifies their advantages and limitations and identifies further research opportunities.

LITERATURE REVIEW

According to Tung, *et al.* 2020, a shift is occurring within automotive from key powertrain related components to digitally enabled electrification of drive systems accelerating HEVs and EVs. This shift, for enhancing fuel economy and lowering emissions, calls for high-performance driveline lubricants and thermal coolants that will have electrical and thermal characteristics, in addition to their general operating roles. Therapeutic fluids demand infallible dedicated solutions in thermal cooling, bearing protection, corrosion protection and sludge management for long life and better performance of electrified systems. This review covers trending topics on electrification of automobiles and new age drive-line oils and coolants. It concerns itself with the future of energy conversion, drivetrain durability, and thermal issues, including state of the art cooling systems for battery, motor, and power electronics. This paper draws on their future possibilities concerning the evolution of automotive propulsion systems.

According to Malik, *et al.* 2016, the high emission levels, and growing vehicle ownership within the transportation sector demand sustainable strategic interventions. With the availability of renewable sources of power and modern batteries, electric or hybrid electric cars that use electricity, gas or both, respectively, offer a credible solution. However, there is still the problem of thermal management, battery disposal, a restricted range of battery-free vehicles, and safety. However, the drawbacks such as poor thermal conductivity, and high cost of the more advanced materials need further development. On the rise of battery – costs and charging infrastructure seem favorable while sodium-ion, and dual-carbon batteries appear to compensate for existing limitations.

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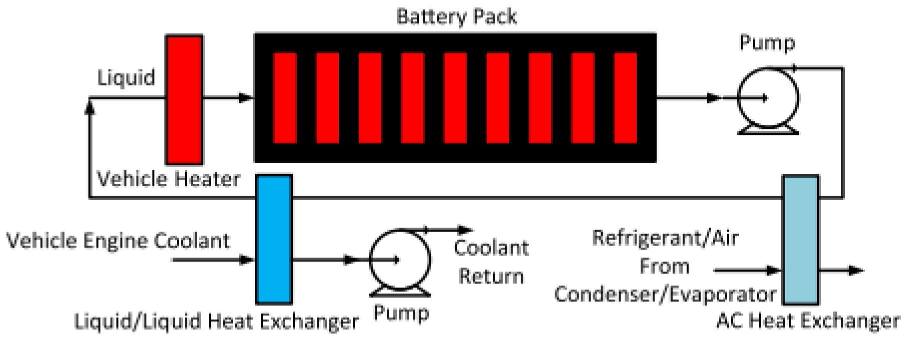
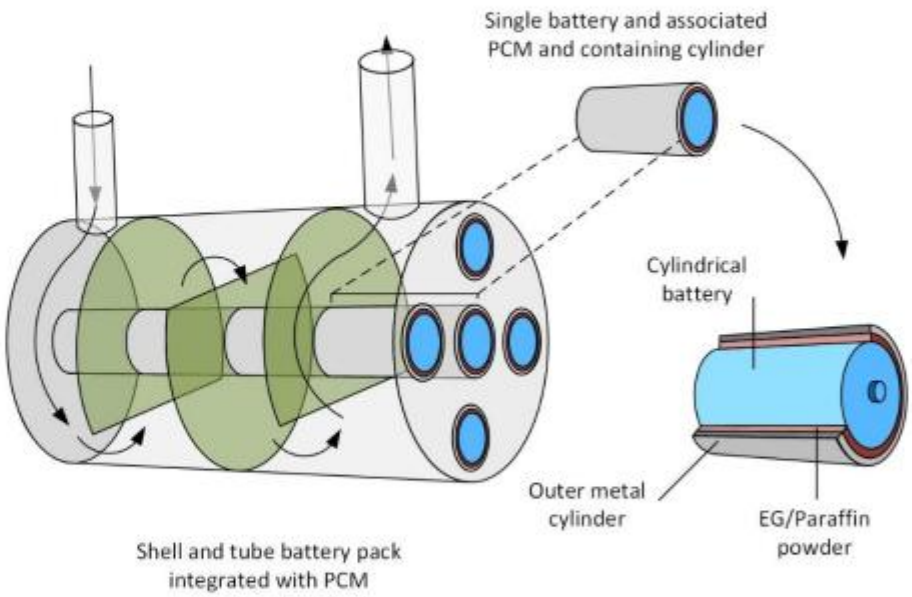


(Source: Malik, *et al.* 2016)

Figure 1: General schematic of thermal management system for a Li-ion battery using a liquid coolant

According to Al-Zareer, 2019, thermal systems are important in controlling temperatures of lithium-ion batteries applicable in hybrid and electric cars. In this research, new techniques for battery thermal management are designed and simulated to analyze thermal and electrochemical efficiency. The key performance indicators include the highest level of battery temperature and the distribution of temperature in battery packs. Analysis shows that pool-based systems are beneficial especially for cylindrical batteries, lowering peak temperatures by 28% to 40% when 30% of battery height is covered during high-current discharge cycles. To obtain similar reductions in overall height of prismatic batteries, 80 % height coverage is needed. Among the structures for cooling, the tube-based system with the use of an aluminum cold plate including coolant-filled tubes is most suitable for prismatic ones. 80% less coolant is required while providing the best thermal characteristics and thermal distribution. Inherent in these systems are response times that are approximately ten fold that of other traditional thermal management systems such as liquid and air cooling. The response time of the pool-based system is therefore 1.7% of the cycle, while that of mini-channel cold plate cooling is 17%. The results presented herein show that these developments can make a massive difference in thermal regulation for battery capacity and durability.



(Source: Al-Zareer, 2019)

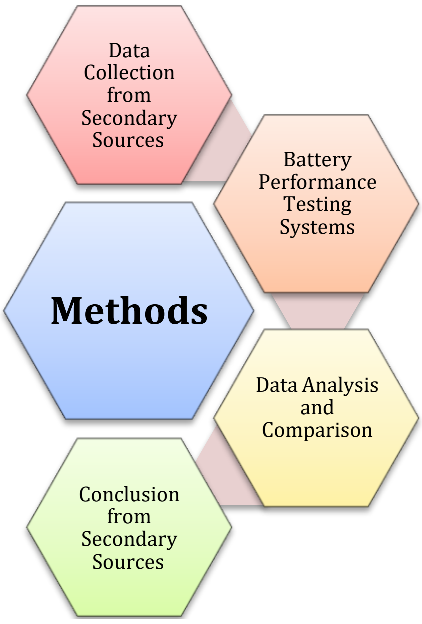
Figure 2: Schematic diagram of the integrated shell and tube heat exchanger integrated with PCM for cylindrical battery cooling

Methods

In the present research, an attempt has been made to assess various thermal management concepts using a lab-scale battery performance testing system for HEV and EV battery systems. The testing system was intended to represent realistic application conditions as well as the performance of different cooling methods (Chen *et al.*, 2023). As this study has focused on quantitative, secondary data was used in order to investigate the performance of thermal management systems of battery packs by employing previous studies and findings.

Data Collection from Secondary Sources

The information for this paper was gathered from querying articles from journal databases accredited by academic institutions, business and industrial magazines and academic journals that capture issues related to thermal management of battery systems in electric vehicles. These secondary research sources gave information on the practicability of various thermal management techniques including liquid cooling, PCM, and combined techniques. Information about the thermal characteristics of Lilo batteries under different conditions, heat production during the charge-discharge cycles, temperature distribution, and cooling efficiency were obtained from these papers.



(Source: Self-Created)

Figure 3:- Methods

Battery Performance Testing Systems

The test system setup used in this study was based on the methodologies contained in the secondary sources. The testing systems primarily focused on evaluating three types of cooling solutions: The topics within it are the methods of active cooling instruments, liquid cooling, phase change materials, and systems, and the systems are the combination of both.

Liquid Cooling Systems: The liquid cooling system performance metrics were derived from data that was obtained from studies that exposed battery packs through high current discharge and charge cycles (Singla et al., 2024). The secondary data offered specific characteristics in regards the coolant types, coolant flow rates, as well as the heat exchange strategies for a uniform temperature distribution of battery cells.

Phase Change Materials (PCMs): Relevant case studies based on PCM cooling systems were employed to evaluate the mechanisms of heat exchange when they absorbed and released heat during the process of temperature variations. Secondary information was information on the thermal management capability of PCMs in regulating battery temperatures especially during deep discharge regimen.

Hybrid Cooling Systems: Experiments of combined liquid cooling as well as Phase Change Material (PCMs) was also investigated by secondary data (Bai et al., 2020). The hybrid systems present active and passive cooling, and for this assessment, secondary data were adopted to illustrate how battery temperature is regulated by liquid cooling and PCM to realise its highest efficiency.

Data Analysis and Comparison

After the data was obtained, analyzing it helped the researchers compare different techniques of cooling to come up with the best solutions for battery thermal management. Feasibility analysis was conducted with the objective of identifying the advantages and limitations of each cooling system. Quantitative measurements were obtained from the secondary sources and these numbers were used to quantify the overall thermal management performance.

Conclusion from Secondary Sources

Comparing the secondary data found in this research, liquid cooling remains as the fast and effective cooling method, while the PCMs are cheap and self-cooling measures. Researchers have also noted that using both approaches was the most effective, but it also adds increased cost and program complexity.

This method of using secondary data from existing studies proved useful in developing a broad understanding of the current status of battery thermal management systems that are free from the gathering of primary data and basic experimental. Information obtained from secondary research assisted in evaluating suitable thermal management approaches for HEV as well as EV.

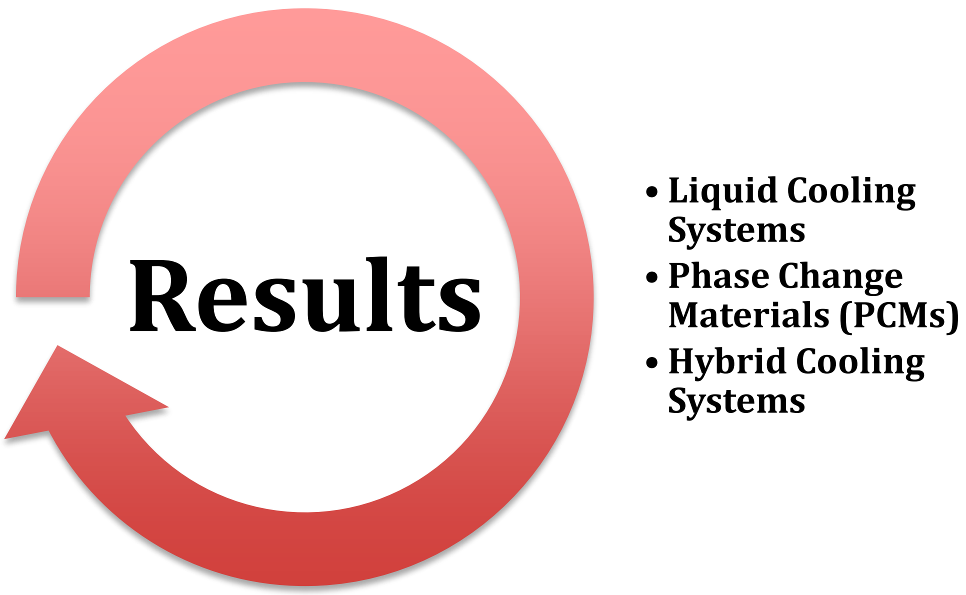
Results

Depending on the results obtained from the lab-scale battery performance testing systems with the help of secondary data, it has been observed that liquid cooling, PCMs and hybrid systems are quite different from each other as far as the cooling of battery temperatures is concerned.

Liquid Cooling Systems: Liquid cooling was deemed as the best solution for fast cooling and stable temperature management within the battery pack (Liu et al., 2022). Research pointed out that liquid cooling can lower peak temperatures by as much as 40%, which is suitable for a high power discharge activity. However, these systems include few exclusions like pumps, heat exchangers and coolant reservoirs thus making the battery pack complex and less cost effective.

Phase Change Materials (PCMs): Overall, PCMs had moderate performance with regard to temperature stability of batteries, specifically for low to medium power discharge conditions. These materials stored heat during the high-temperature cycles and rejected it during when the temperature came down. But the heat dissipation rate of PCMs was slower than liquid cooling, and the cooling power was somewhat confined to the heat capacity of the PCM.

Hybrid Cooling Systems: Compared to liquid cooling only and PCMs only, use of hybrid systems offered the best thermal management. The liquid cooling system solved the issue of increased temperature under the conditions of high current discharge, and PCMs preserved the long-term low temperature (Xu et al., 2020). Hybrid systems also proved to regulate the ideal test temperature through the use of cycling to recommend the appropriate levels of both active and passive cooling.



(Source: Self-Created)

Figure 4:-Results

DISCUSSION

The study implies that none of the cooling methods reviewed in this paper may be perfect for all the conditions. Water cooling is the fastest and most efficient method for cooling but it has its issues, and that is complexity and costs (Islam and Iyer-Raniga, 2022). PCMs, therefore, provide a passive solution less aggressive than the RAS for cooling and heat removal from electronic apparatuses; however, the rate of dissipation of heat from these fluids is sluggish in the course of cyclic high power usage. Thus, the systems with both active and passive cooling work in both options, cool fast when needed and do not fluctuate with temperature variations.

One of the important sources of study limitation is that different performance of these systems highly depends on battery type, size and utilization pattern. For example, whereas liquid cooling is probably optimal for high)-power and fast charging applications, it can be overkill in low-power applications (Farivar et al., 2022). Likewise, accuracy of PCMs can be dependent to a great extent on design of the battery and its operational conditions.

However, the results gathered herein underscore the need for a suitable thermal management system capable of meeting the future thermal management needs of HEV and EV battery systems in order to prevent failures, accidents or reduced efficiency.

Future Directions

It is possible that further studies can be made in the direction of enhancing the possibility of application of hybrid cooling systems in commercial EVs. There is also potential in the refinement of materials for application in cooling systems, including novel graphene see-through heat spreaders with greatly improved effective conductivity compared to many traditional heat spreaders (Farivar et al., 2022). Further down, there are smart, adaptive cooling systems to predict and change the amount of cooling needed using sensors as well as machine learning, with reference to the performance of the battery could save energy and be more effective.

One promising research area is development of new materials for PCMs and coolants that are eco-friendly and cost efficient (Roth *et al.* 2022). Because battery cooling systems are an important part of electric vehicles, minimizing the adverse effects of increasing demand for EVs will be critical in the future.

Finally, more research should be conducted on how to increase the system integration efficiency of thermal management systems with battery management systems (BMS) to improve the cooling performance and battery performance simultaneously.

CONCLUSION

In conclusion, this paper has established that thermal management is a critical success factor for battery systems used in HEV and EVs because it determines the safety, performance, and durability of such batteries. Liquid cooling is still the best way to dissipate heat quickly; however, PCMs present a more straightforward cooling technique. It has been identified that a system with a balance of both active and passive approaches gives the best solution to battery temperature control. It may be concluded that it is only crucial to select a proper approach to thermal management depending on the type of battery and vehicle for which it is used.

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