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A Review of Liquid Cooling Thermal Management Systems for Batteries in Electric Vehicles

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ABSTRACT: *Electric vehicle (EV) batteries generate significant amounts of heat during both operation and charging processes. If this heat is not properly managed, it can lead to decreased battery performance, reduced lifespan, and even pose safety risks such as thermal runaway. Therefore, an effective thermal management system is crucial for maintaining optimal battery performance and ensuring vehicle safety. This review provides an in-depth analysis of liquid cooling systems for battery thermal management in electric vehicles. It explores various liquid cooling technologies, including single-phase and two-phase cooling, and evaluates their effectiveness in maintaining temperature uniformity across battery cells. The review also highlights key design considerations, such as the choice of coolant fluids, heat exchanger configurations, and the integration of cooling systems within the battery pack. Research indicates that liquid cooling systems can achieve better thermal regulation, improve battery efficiency, and extend the operational life of the battery by keeping the temperature within the optimal range.*

KEYWORDS: *Electric vehicle,liquid cooling,battery cells, thermal management.*

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I. INTRODUCTION

Electric vehicles (EVs) have transformed the automotive industry by offering a cleaner, more sustainable mode of transportation that reduces greenhouse gas emissions and reliance on fossil fuels[1, 2]. This innovation has been largely propelled by advancements in battery technology, which enable EVs to store and use electric energy efficiently. The lithium-ion battery, with its high energy density, is the dominant technology used in modern EVs, supporting a range of vehicle functions, from acceleration to climate control [3,4,5]. However, despite these advantages, battery performance is heavily influenced by temperature, posing a significant challenge for electric vehicle reliability and safety. Proper battery thermal management is crucial, as excessive heat generation during high-speed charge and discharge cycles can lead to rapid battery degradation, reduced lifespan, and even critical safety risks, such as thermal runaway. Managing battery heat has thus emerged as a critical focus in EV technology development. As batteries undergo intense charge and discharge cycles, particularly during fast charging and high-speed driving, they generate substantial amounts of heat [6,7,8]. Studies have shown that this heat, if not adequately managed, can significantly increase battery temperature, leading to issues such as decreased efficiency, capacity loss, and accelerated aging. Moreover, external factors, including high ambient temperatures, further impact battery thermal behavior, exacerbating the challenge of temperature control [9,10]. To address this, researchers have proposed various modeling approaches to study battery thermal behavior. Electrochemical-thermal and electrical-thermal models, for instance, have been developed to simulate the heat generation and distribution within battery cells [11,12]. These models aid in predicting thermal responses and allow engineers to explore various cooling strategies, optimizing thermal management designs for real-world applications.

Over the past few decades, extensive research has been conducted on Battery Thermal Management Systems (BTMS) for EVs, spanning both simulation-based and experimental studies. BTMS technology has evolved to incorporate multiple cooling approaches, generally classified into three main types: air cooling, liquid cooling, and phase change material (PCM) cooling [13,14,15]. Air cooling, as the simplest form, relies on airflow to dissipate heat, making it cost-effective and easy to integrate. However, its limited cooling efficiency restricts its applicability, especially in high-power or high-density battery systems. PCM cooling, which utilizes materials that absorb and release heat through phase changes, offers a passive solution with higher heat absorption capacity but has limitations in controlling temperature fluctuation and long-term reliability. Among these methods, liquid cooling has emerged as one of the most effective solutions for maintaining battery temperature within a safe range, providing greater cooling capacity, uniformity, and efficiency compared to other methods.Therefore, this paper summarizes key studies conducted in recent years on liquid cooling strategies, highlighting the strengths, limitations, and future potential of these systems. Furthermore, it consolidates current knowledge on liquid cooling systems, providing researchers and engineers with a valuable resource for designing the next generation of EV BTMS.

II. LIQUID COOLING THERMAL MANAGEMENT SYSTEMS

Liquid cooling systems in BTMS utilize coolants often water glycol mixtures to actively manage battery temperature through conduction and convection. These systems are widely regarded for their ability to maintain temperature uniformity across battery cells, which is critical for prolonging battery life and ensuring consistent performance. Liquid cooling can be further subdivided into direct and indirect liquid cooling systems

Direct Liquid Cooling (DLC):In direct liquid cooling, the coolant directly contacts the battery cells. This allows for more efficient heat transfer as the coolant can absorb heat directly from the cells. In [16], researchers proposed two systems: liquid-filled battery cooling systems (LfBS) and liquid-circulated battery cooling systems (LcBS), as shown in Figure 1. Their findings indicated that LfBS is well-suited for moderate discharge rate batteries (2 C) in conditions where there is no liquid circulation, particularly in low ambient temperatures. Furthermore, for higher discharge rates, the LcBS effectively kept the battery surface temperature within a desirable range. This system allowed the heat absorbed by the heat transfer fluid (HTF) to be released either into the air re-circulated from the air conditioning system or directly to the outside air.

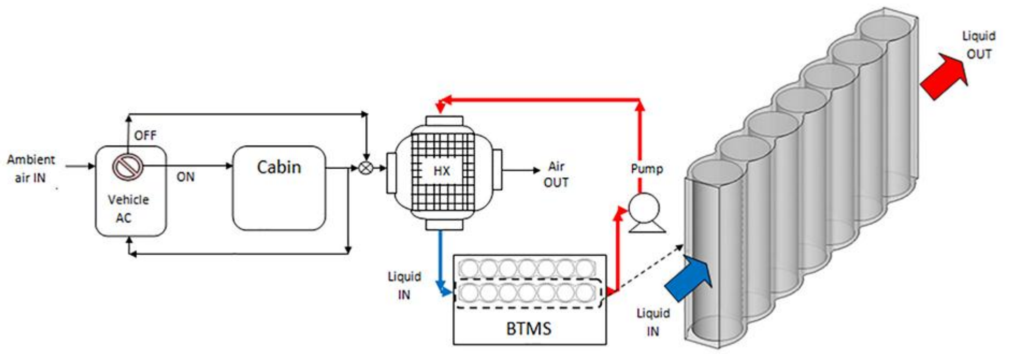

Figure 1. Structure the Liquid circulated arrangement for BTMS[16]

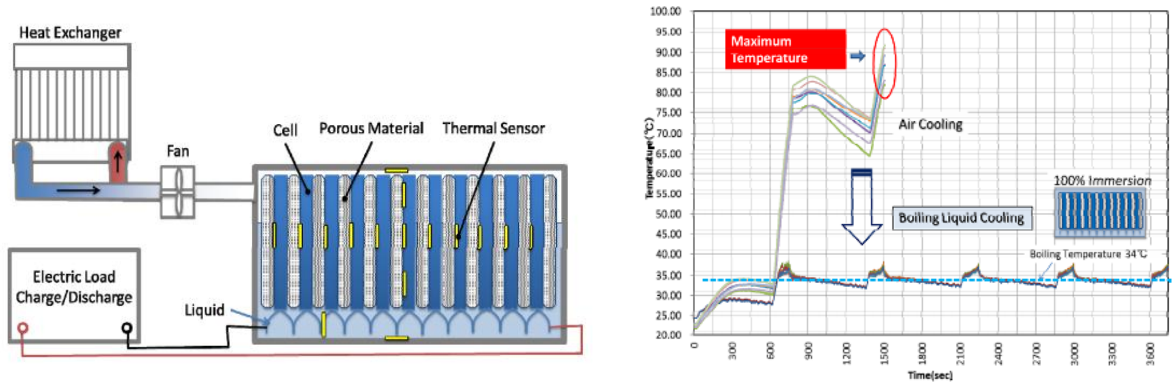

Figure 2. Structure and results of boiling fluid type cooling system for BTMS [17]

Hirano et al. [17] introduced a boiling-based battery cooling technique, as shown in Figure 2, utilizing hydrofluoroether (Novec-7000) and perfluoroketone (Novec-649) as heat transfer media. The boiling points for Novec-7000 and Novec-649 are 34°C and 49°C, respectively.Although both methods are effective, they each require the use of highly reliable, non-conductive coolants to prevent potential short circuits or battery damage.

*Indirect Liquid Cooling (ILC):*In indirect liquid cooling, the coolant circulates through channels or plates that are thermally connected to the battery cells but do not directly contact them. The heat is transferred from the battery cells to the thermal plates, which are then cooled by the circulating coolant.

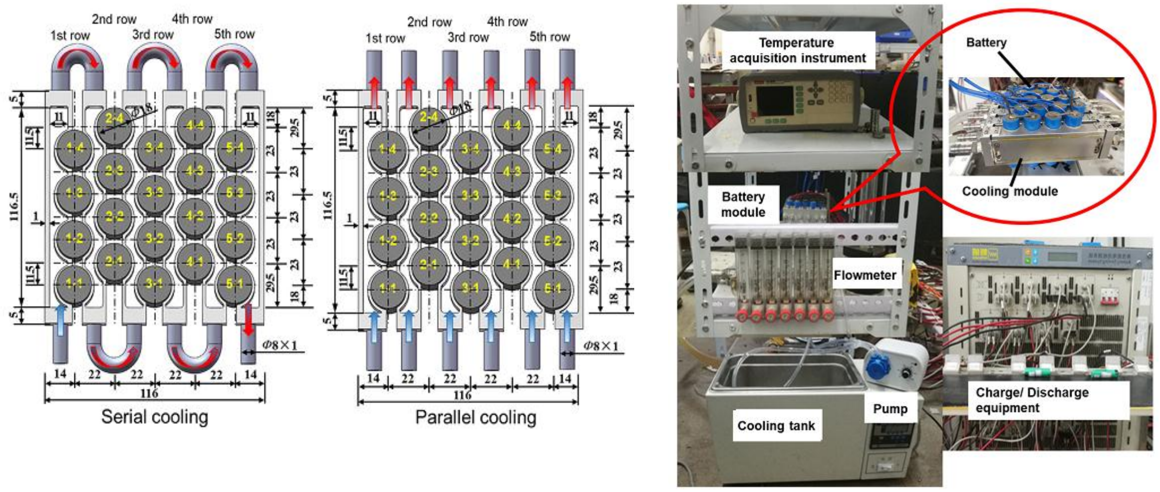

Figure 3. The cooling liquid flow into the tubes [18]

In [18], a liquid cooling solution using thermal dissipation through cooling tubes is proposed, as shown in Figure 3. This design involves circulating coolant through tubes placed strategically around the battery cells, enabling efficient heat transfer. Meanwhile, in [19, 20], liquid cooling solutions using heat-dissipating plates are suggested as an alternative approach, as shown in Figure 3. Both tube- and plate-based designs have shown effectiveness in maintaining optimal battery temperature, which is critical for enhancing battery life, efficiency, and safety in electric vehicles.

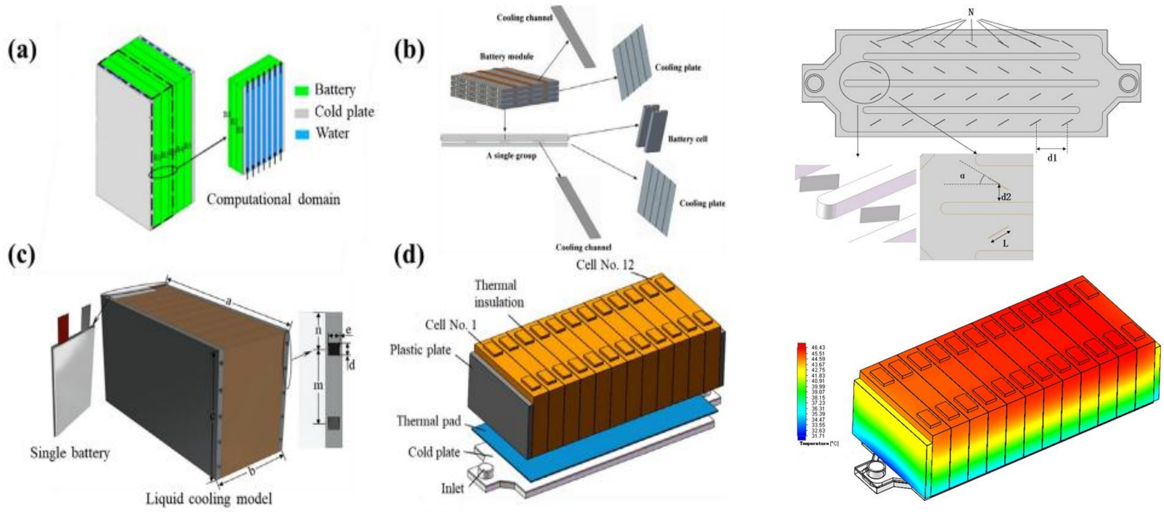

Figure 4. The cooling liquid flow into the cooling plate [19,20]

Development Trends in Liquid Cooling Systems: Although direct liquid cooling and indirect liquid cooling have shown significant improvements in thermal management performance, there are still limitations that need to be addressed. To further enhance the performance of liquid cooling systems, several recommendations have been proposed as follows

(1) Use of environmentally friendly coolants: To make coolant more environmentally friendly, instead of traditional glycol, research neededa focus on non-toxic, recyclable coolants to minimize environmental impact. This trend aligns with the automotive industry's goals for sustainable development and adherence to environmental standards.

(2) Enhanced thermal dissipation with two-phase cooling systems: Two-phase cooling systems are gaining attention due to their high heat dissipation capabilities, absorbing significant thermal energy when the coolant transitions from liquid to gas. This represents a major improvement, allowing the system to operate efficiently at high temperatures without increasing size or weight. This trend is ideal for high-performance EVs, where effective thermal management is critical without compromising overall design.

(3) Lightweight and space-optimized design: To reduce weight and optimize space in EVs, liquid cooling systems are increasingly designed to be compact and lightweight. Research needed to focused on developing

fluid circulation channels and heat dissipation surfaces that maximize efficiency within a limited space. Additionally, new cooling systems integrate modular technology, allowing easy replacement or maintenance of individual system components.

(4) Integration of smart control technology: To optimize the cooling process and minimize energy consumption, research needed to apply smart control technology with temperature sensors and intelligent controllers is used to monitor and adjust fluid flow based on the battery's temperature.

III. CONCLUSIONS

This paper has highlighted the crucial role of liquid cooling thermal management systems (BTMS) for electric vehicle (EV) batteries in enhancing their performance and ensuring safety. As EV adoption continues to rise, effective thermal management has become a key factor in maximizing battery efficiency, lifespan, and safety. Several conclusions can be drawn from the research: (i) Liquid cooling systems provide significant improvements in thermal management over air-based solutions. These systems are more efficient in maintaining optimal battery temperature by offering better heat dissipation, making them essential for high-performance EVs where thermal stability is critical. (ii) Emerging trends in liquid cooling systems, such as the use of environmentally friendly coolants and two-phase cooling techniques, show great promise in reducing environmental impact while improving thermal efficiency.Overall, liquid cooling systems are a promising solution for EV thermal management, and ongoing research will continue to refine these systems to meet the growing demands of the electric vehicle market.

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REFERENCES

[1]. Wang, J.; Li, Y.; Zhang, Y. Research on carbon emissions of road traffic in Chengdu city based on a LEAP model. Sustainability, 14, 5625, 2022.

[2]. Olabi AG. Bahri as, Abdelghafar AA, Baroutaji a, Sayed ET, Alami AH, RezkH,AbdelkareemMA,Llarge-scale hydrogen production and storage technologies: current status and future directions. IntInternational Journal of Hydrogen Energy, 46(45), 23498-528, 2021.

[3]. Akhtar, M.S.; Bui, P.T.; Li, Z.-Y.; Yang, O.-B.; Paul, B.J.; Kim, S.; Kim, J.; Rai, A.K. Impact of porous Mn3O4 nanostructures on the performance of rechargeable lithium ion battery: Excellent capacity and cyclability. Solid State Ion, 336, 31–38,2019.

[4]. Natkunarajah, N.; Scharf, M.; Scharf, P. Scenarios for the return of lithium-ion batteries out of electric cars for recycling. Procedia Cirp 2015, 29, 740–745.

[5]. Pesaran, A.A. Battery thermal models for hybrid vehicle simulations. J. Power Sources, 110, 377–382, 2002.

[6]. H.S. Hamut, I. Dincer, G.F. Naterer, Exergy analysis of a TMS (thermalmanagement system) for range-extended EVs (electric vehicles), Energy 46, 117–125, 2012.

[7]. H. Jouhara, B. Delpech, R. Bennett, A. Chauhan, N. Khordehgah, N. Serey, S. P. Lester, Heat pipe based battery thermal management: evaluating the potential of two novel battery pack integrations, International Journal of Thermofluids, 12,100115,2021.

[8]. M. Hajialibabaei, M.Z. Saghir, A critical review of the straight and wavy microchannel heat sink and the application in lithium-ion battery thermal management, International Journal Thermofluids, 14,100153, 2022.

[9]. Xu J, Guo ZC, Xu ZM, Zhou X, Mei XS. A systematic review and comparison of liquid-based cooling system for lithium-ion batteries. eTransportation, 17, 100242, 2023.

[10]. Zhang SS, Xu K, Jow TR. The low temperature performance of Li-ion batteries. Journal Power Sources, 115(1):137–40, 2003

[11]. Nie, P.; Siwei, Z.; Aihua, R.; Canhui, Y.; Shuxiao, C.; Zhenlong, L.; Xuan, Z.; Weiwei, D.; Ting, L.; Feiyu, K.; et al. Full-cycle electrochemical-thermal coupling analysis for commercial lithium-ion batteries. Applied Thermal Engineering, 184, 116258,2021.

[12]. Li, H.; Saini, A.; Liu, C.; Yang, J.; Wang, Y.; Yang, T.; Pan, C.; Chen, L.; Jiang, H. Electrochemical and thermal characteristics of prismatic lithium-ion battery based on a three-dimensional electrochemical-thermal coupled model. Journal Energy Storage, 42, 102976, 2021.

[13]. Chunxia Wu, Yalong Sun, Heng Tang, et al. A review on the liquid cooling thermal management system of lithium-ion batteries. Applied Energy, 375, 124173, 2024

[14]. Gang Zhao ,Xiaolin Wang, et al. A review of air-cooling battery thermal management systems for electric and hybrid electric vehicles. Journal of Power Sources, 501, 230001, 2021.

[15]. Amrit Kumar Thakur, Rajendran Prabakaran, et al. A state of art review and future viewpoint on advance cooling techniques for Lithium–ion battery system of electric vehicles, Journal of Energy Storage, 32, 101771. 2020.

[16]. R.D. Jilte a, Ravinder Kumar a, Mohammad H. Ahmadi. Cooling pe rformance of nanofluid submerged vs. nanofluidcirculated,battery thermal management systems. Journal of Cleaner Production, 240, 118131, 2019.

[17]. Hirokazu Hirano; Takamitsu Tajima; Takeru Hasegawa; Tsuyoshi Sekiguchi; Minoru Uchino. Boiling Liquid Battery Cooling for Electric Vehicle.IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), Beijing, China, 2014

[18]. Haitao Wang, Tao Tao, Jun Xu, XuesongMei ,Xiaoyan Liu, Piao Gou. Cooling capacity of a novel modular liquid-cooled battery thermal management system for cylindrical lithium ion batteries,Applied Thermal Engineering, 178, 115591, 2020.

[19]. Q.L. Yue , C.X. He, M.C. Wu, T.S. Zhao. Advances in thermal management systems for next-generation power batteries, International Journal of Heat and Mass Transfer, 181,121853, 2021.

[20]. Xiaoming Xu, Guangyao Tong, Renzheng Li. Numerical study and optimizing on cold plate splitter for lithium battery thermal management system. Applied Thermal Engineering, 167, 114787, 2020.