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TOWARDS THE IMPLEMENTATION OF LOOP HEAT PIPES IN AUTOMOTIVE BATTERY THERMAL MANAGEMENT SYSTEMS

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1. ABSTRACT

This paper presents the results of a series of investigations aimed to aid the implementation of a battery thermal management system for electric vehicles based on loop heat pipes. The LHPs can passively transfer heat from the battery pack to a remote chiller, without consuming parasitic power. Experiments demonstrate that the proposed solution can enable fast 3C charging and maintain satisfactory battery temperatures from -20°C to 50°C ambient. Compared to passive air cooling, the system reduces peak temperatures during fast charging by 7.9°C and more than doubles battery lifetime. The results highlight the potential of passive two-phase heat transfer for automotive thermal management.

2. INTRODUCTION

Electric vehicles (EVs) are growing in popularity as a means to reduce greenhouse gas emissions from the transportation sector. However, limited driving range, long charging times, and high costs continue to hinder widespread EV adoption. Efficient thermal management of the EV battery pack is critical to addressing these limitations. In particular, the battery temperature must be kept within 25-40°C for optimal performance and safety [1]. To this end, a battery thermal management system (BTMS) based on loop heat pipes (LHPs) and graphite sheets has been proposed and investigated by the Authors. LHPs can passively transfer heat from the battery pack to a remote chiller, while the graphite sheets provide thermal coupling between cells. Previous studies have demonstrated the potential of this LHP-BTMS to outperform standard active liquid cooling approaches in limiting battery temperatures during fast charging [1] [2]. This work summarizes key findings from several works with the aim to outline the path towards implementing LHPs in automotive BTMS to enable faster charging, extended range, lower costs, and simplified maintenance compared to current state-of-the-art systems.

3. METHODOLOGY

The LHP-BTMS configuration developed by the authors is illustrated in Fig. 1. LHPs are two-phase heat transfer devices that utilize passive evaporation and condensation cycles of a working fluid to transport heat [2] . In this system, LHPs are located at the base of each battery module, where they can absorb heat from the cells and transfer it to a chiller that is part of the vehicle's HVAC system. This eliminates the need for separate cooling loops and reduces system complexity. The graphite sheets are inserted between the cells within each module. The graphite provides excellent

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thermal coupling in the plane of the sheets due to its woven structure, facilitating lateral heat spreading from hot spots. But the through-plane conductivity is low, which thermally isolates adjacent cells. The proposed design was developed and studied thanks to a 1-D Lumped Parameter Model and an experimental demonstrator, which details can be found in [1].

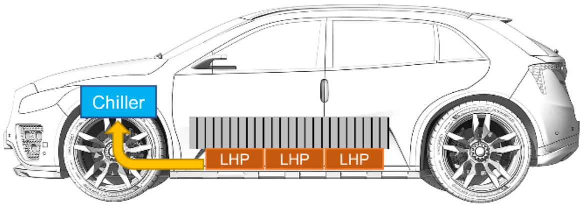

Fig. 1. Illustration of the proposed BTMS design based on LHPs. The black lines represent the graphite sheets in-between the cells.

4. RESULTS

To better address automotive manufacturers' questions about the real-world applicability of this design, the authors have conducted the following investigations: Exploring the use of a new "green" fluid, 3M Novec649, in the cooling system; Assessing the system's performance at various ambient temperatures ranging from -20°C to 50°C; Comparing the proposed design with other Battery Thermal Management Systems (BTMS), such as air cooling and liquid cold plates, across a range of scenarios (including a simulated test drive from London to Liverpool); Evaluating the performance of the proposed design against passive cooling using free convection. These investigations aim to provide a comprehensive understanding of the design's performance and suitability for real-world automotive applications.

Non-Pollutant fluid: a gap on the research was identified, where heat pipes researchers worldwide use classical fluids such as water, ethanol, acetone or FC-72 due to their high merit numbers [4]. However, these fluids present either freezing complications or toxicity, flammability and pollution issues, which would make them non-suitable for automotive industry. Hence, for the first time, 3M© Novec© 649 fluid was used as LHP working fluid. This fluid has a suitable boiling point (49°C), it is not toxic, not flammable and has ODP of 0 and GWP of 1, making it a perfect candidate for BTMS automotive applications. Experimental investigations have shown that, when compared to using ethanol, system thermal performances when using Novec© 649 showed no significant decrease, i.e., maximum cell temperature increased by only 0.7°C [3].

Operation at different ambient temperatures: Automobiles needs to be designed to consistently perform regardless of where they are driven. As a result, the effect of ambient temperature should be minimised. It is well known that ambient temperature has a negative effect on EVs range, hence why the performance of the proposed BTMS was evaluated in wide range of external temperatures. Firstly, the cooling performances in hot environments was studied; following, the LHP-system behaviour at low temperatures was examined. In fact, being the LHP a passive system, it will activate and cool down the batteries even if it is not required to, thus the second part of the study was focused on evaluating the delayed effect that the proposed BTMS was having on the heating process. The experimental test-rig was placed inside an environmental chamber and temperature varied from -20°C to 50°C. Results showed that the BTMS worked well at high temperatures, allowing 3C fast charging even when the temperature is at 40°C. It was noted that during heating from low temperatures (100 W for 15 minutes), the LHP-based BTMS would reduce the final cell temperature by 1 °C lower, compare to when not used. However, this negative effect is greatly outmatched by the benefit provided during cooling at high temperatures. On the back of these successful experimental results, further numerical simulations on a 12-cell module verified the system can maintain cell temperatures within optimum levels during aggressive 3C fast charging across a range of ambient temperatures. Compared to free convection cooling alone, the LHP-BTMS reduced peak cell temperatures by up to 7.9°C [4].

Ageing comparison: thanks to two experimentally validate numerical models, one in COMSOL and one on Octave, it was possible to compare passive air cooling and LHP cooling applied to lithium-ion cylindrical battery module, in terms of temperature, ageing rate, and current distribution. It finds that LHP cooling provides much better temperature uniformity and slower ageing compared to just air cooling. In particular, with the LHP-based BTMS coupled with an aluminium plate, current maldistribution could be reduced from 1.05 A to 0.05 A and operative life extended from 146 cycles to 310 cycles, so more than doubled [5].

3. CONCLUSIONS

This work demonstrates the potential of using loop heat pipes integrated with graphite sheets as a passive thermal management system for electric vehicle battery packs. The results from the investigations presented herein showed that the LHP can allow BTMS to provide effective cooling during fast charging and across a wide range of ambient temperatures from -20°C to 50°C, to effectively use low-pollutant and safe working fluid and to significantly reduce the temperature induced battery ageing. Key benefits over traditional active liquid-based systems include no parasitic power losses, lower complexity, reduced maintenance needs, and elimination of separate cooling loops. These results highlight the advantages of passive two-phase heat transfer for automotive thermal management. Ongoing research is focused on expanding the experimental validation and evaluating performance at the full battery pack level.

REFERENCES

[1] M. Bernagozzi, A. Georgoulas, N. Miché, C. Rouaud and M. Marengo, Novel battery thermal management system for electric vehicles with a loop heat pipe and graphite sheet inserts, *Applied Thermal Engineering,* 194 (2021), 117061.

[2] Y. Maydanik, Loop heat pipes, *Applied Thermal Engineering,* 25 (2005), 635-657.

[3] M. Bernagozzi, N. Miché, A. Georgoulas, C. Rouaud and M. Marengo, Performance of an Environmentally Friendly Alternative Fluid in a Loop Heat Pipe-Based Battery Thermal Management System, *Energies,* 14 (2021), 7738.

[4] M. Bernagozzi, A. Georgoulas, N. Miché and M. Marengo, Experimental analysis of the influence of ambient temperature for a Loop Heat Pipe based Battery Thermal Management System, *Experimental and Computational Multiphase Flow*, (2024) *(accepted).*

[5] H. He, A. Fly, X. Chen, W. Malalasekera and M. Bernagozzi, Ageing comparison of passive battery thermal management systems: air cooling and loop heat pipes, *Applied Thermal Engineering, (2024)* (*submitted*).