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INTEGRATED TWO-PHASE IMMERSION COOLING OF ELECTRIC VEHICLE BATTERIES WITH ORGANIC RANKINE CYCLE

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1. ABSTRACT

Two-phase immersion cooling has the potential to maintain electric vehicle batteries at uniform temperatures thus offering effective battery thermal management. In this study, the effects of changing the refrigerant used, and varying the space between each battery cell were investigated using Computational Fluid Dynamics (CFD) simulations. Results showed that all used refrigerants achieved similar temperature distribution, but when Novec 649 was used the highest amount of electrical power could be recovered from cooling 27,000 battery cells, an amount used in commercial lorries, by enabling the production of electricity using the Organic Rankine cycle (ORC).

2. INTRODUCTION

One of the main factors that affect battery performance in electric vehicles is temperature. Cold temperatures increase charging time and decrease acceleration due to an increase in internal resistance [1]. Cabin preconditioning and battery thermal management, such as resistive heating, can mitigate these effects [1]. Hot temperatures increase battery degradation and charging time and decrease the vehicle range [1]. There are several methods to cool vehicle batteries, these include using cooling tubes, micro-channelled cooling plates, and single and two-phase immersion coolers [2], [3].

In immersion cooling methods, the battery cells are immersed in the cooling fluid thus the battery cells surfaces are in contact with the cooling fluid leading to better cooling performance in terms of achieving low and uniform battery temperature. Cooling performance is further improved by utilising the refrigerant's high latent heat of vaporisation [3] and harnessing the waste heat to drive an organic Rankine cycle.

3. METHOD

Figure 1 shows the two-phase immersion cooler containing 16 of the 21700 battery cells with inlet at the base and outlet at the top. A polyhedral mesh was used, and a mesh sensitivity study was carried out where 89,666 cells produced accurate results with no excessive computing time. For a 1C discharge rate, each battery cell generates $12{,}202 W/m^3$ of heat [4] which needs to be dissipated by the immersion cooling system.

Seven dielectric refrigerants were investigated, to assess the impact of changing physical and chemical properties whilst considering environmental impact and the effect battery spacing has on cooling performance. Each refrigerant is pressurised to have a boiling point of 30°C. At the inlet, the refrigerant is a liquid and at

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*Corresponding Author: axw031@student.bham.ac.uk the outlet, it is a vapour. The liquid level is maintained 20mm above the top surface of the battery cells by controlling the mass flow rate at the inlet. Each cell in the system was separated by 5mm, as shown in Figure 1. The simulation was carried out using the k-epsilon model and the Lee evaporation condensation model.

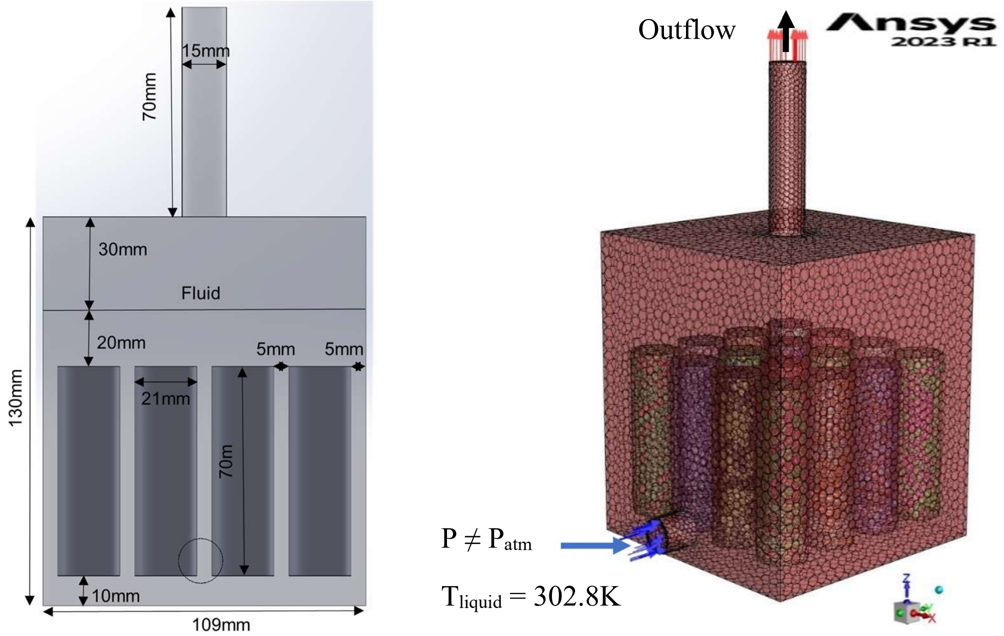

Figure 1 - Immersion Cooler System: Left – Dimensions. Right – Polyhedral Mesh.

4. RESULTS

Figure 2 shows the battery temperature distribution for refrigerant Novec 649 highlighting that the cells have uniform temperatures, but the central 4 cells experienced slightly higher temperatures. Table 1 shows that the cooling performance of the seven investigated refrigerants was similar with less than a 0.2K difference between them. However, the pressure and flow rates required to achieve this performance varied.

Results also showed that reducing the cell spacing from 5mm to 0.5mm produced a negligible effect on the cell temperature. As the temperature difference is negligible this could allow manufacturers to condense their battery packs to increase capacity or to save space.

Table 1 - CFD Refrigerant Cooling Results

Refrigerant	Pressure (MPa)	Mass Flow Rate (kg/s)	Minimum Temperature (K)	Maximum Temperature (K)	Temperature Range (K)
R134A	0.7702	$2.671\text{x}10^{-5}$	303.3985	303.4351	0.0366
R401A	0.8897	$2.537\text{x}10^{-5}$	303.4005	303.4382	0.0377
Novec 7000	0.0867	$3.289\text{x}10^{-5}$	303.4045	303.4327	0.0282
R764	0.4623	$1.316\text{x}10^{-5}$	303.267	303.2894	0.0224
RC318	0.3656	$4.450\text{x}10^{-5}$	303.4586	303.4909	0.0323
Novec 649	0.0497	$4.858\text{x}10^{-5}$	303.4727	303.5066	0.0339
R245fa	0.1778	$2.444\text{x}10^{-5}$	303.365	303.3927	0.0277

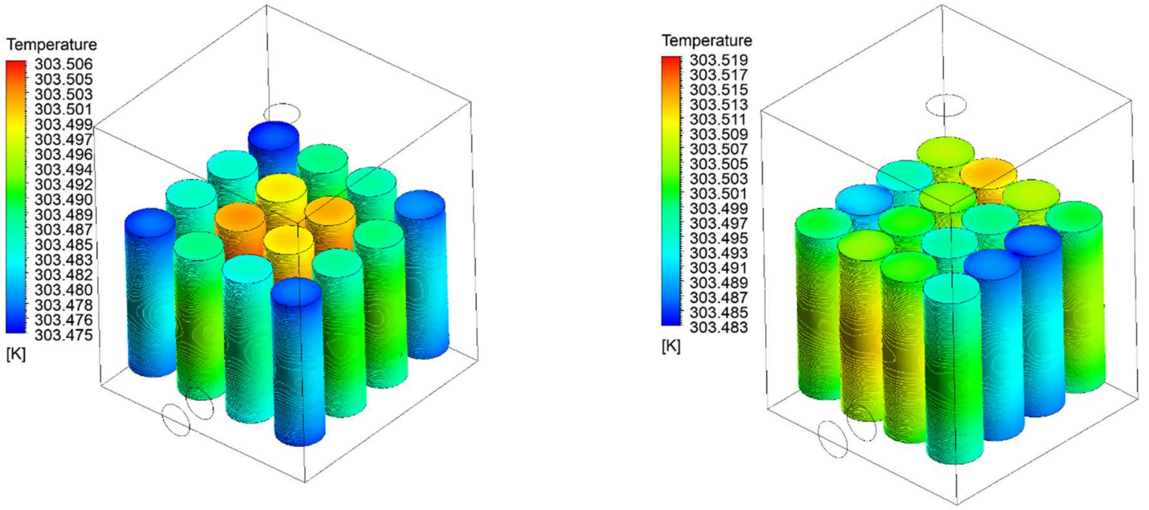

Figure 2 - Battery cells temperature distribution of Novec 649, left 5mm spacing, right 0.5mm spacing.

Energy is recovered using the ORC. Efficiency and power recovered can be calculated using the refrigerant mass flow rates and enthalpies at each stage of the ORC. Condenser inlet temperature (17°C), turbine outlet temperature (23°C), and turbine (51%) and pump efficiencies (80%) used were based on Hu et al., [5]. The efficiency and power recovered from 27,000 battery cells ranged from a minimum of 0.3% and 0.4kW for R764 up to 2.16% and 2.88kW for Novec 649. The results vary due to the different effect temperature and pressure changes have on the refrigerant enthalpy.

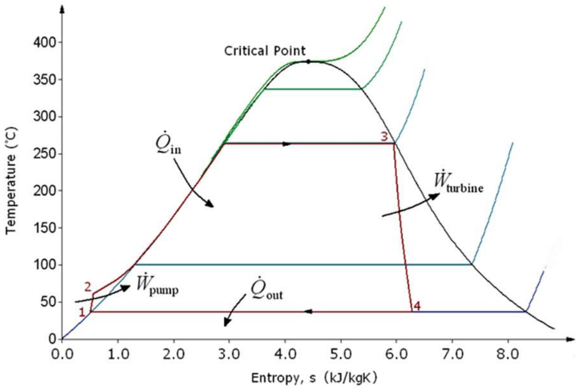

Figure 3 - ORC - (Scientific Library, 2024)

5. CONCLUSIONS

This study investigated the thermal management of 21700 cylindrical battery cells using two-phase immersion cooling using various refrigerants and battery spacings. Results showed that two-phase immersion cooling is an effective method of battery cooling and provides insight into a novel thermal management system.

REFERENCES

[1] *Lindgren, J. and Lund, P.D., Effect of extreme temperatures on battery charging and performance of electric vehicles, J. of Power Sources, 328 (2016), 37-45.*

[2] *Panchal, S., Gudlanarva, K., Tran, M., Fraser R., Fowler, M., High Reynold's number turbulent model for micro-channel cold plate using reverse engineering approach for water-cooled battery in electric vehicles,* Energies, *2020,* 13*(7), 1638.*

[3] *Roe, C., Feng, X., White, G., Li, R., Wang, H., Rui, X., Li, C., Zhang, F., Null, V., Parkes, M., Patel, Y., Wang, Y., Wang, H., Ouyang, M., Offer, G., Wu, B., Immersion cooling for lithium-ion batteries – A review. J. of Power Sources. 525 (2022), 231094.*

[4] *Lin, C., Wen, H., Liu, L., Liu, S., Ma, T., Fan, B., Wang, F., Heat generation quantification of high-specific-energy 21700 battery cell using average and variable specific heat capacities, Applied Thermal Engineering, 184 (2021), 116215*

[5] *Hu, Z., Fan, C., Gao, W., Chen, Y., (2023) Experimental study of a miniature organic Rankine cycle unit using ocean thermal energy. Energy Conversion and Management, 293 (2023).*