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Experimental Analysis on Thermal Performance of Lithium-ion Batteries during Charging using Pulsating Heat Pipe under Influence of Base Fluid and Graphene Nanoplatelates Nanofluids

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Abstract

Automakers have been forced to produce more environmental friendly automobiles due to the need to cut emissions and the use of fossil fuels. The Lithium-Ion Batteries (LIB) are most common source of energy for Electric Vehicles (EVs). The pursuit of a reliable and secure cooling solution for LIB thermal management is still ongoing. This article uses a Pulsating Heat Pipe (PHP) with a circular cross section to experimentally study lithium-ion batteries at various charging C-rate (2C, 1.5C and 1C) with different Filling Ratios (FR) of 40%, 50% and 60%. The water-ethanol mixture is chosen as the working fluid. The water-ethanol solution's Volume Ratio (VR) is 40:60, 50:50 and 60:40. A mass concentration of 0.1% to 1% of Graphene Nanoplatelates (GNP) nanofluid is introduced. According to experimental data, when compared to other filling ratios and volume ratios, the pulsating heat pipe with 40:60 volume ratio of water-ethanol solution and 50% filling ratio showed higher heat transfer performance during 1C charging. The concentration of 0.6% by mass of GNP further accelerates heat transfer and lowers the evaporator temperature to 44.60C when compared to a mixture of water and ethanol. The pulsating heat pipe with GNP nanofluids and a water and ethanol mixture is a viable choice for cooling LIB.

Major Findings: *The lithium-ion battery pack temperature reduced from a peak of 99.1°C to 48.4°C during 1C charging. Further enhancement with 0.6 wt% Graphene Nanoplatelets (GNP) nanofluids lowered the average evaporator temperature to 44.6°C, marking a 3.8°C improvement over the base fluid.*

Keywords: *Graphene Nanoplatelates, Lithium-ion Battery Cooling, Pulsating Heat Pipe, Working Fluids*

1.0 Introduction

In current decade, Electric Vehicles (EVs) have gained increasing value due to their low emissions and reduced noise levels. LIBs are extensively utilized in electric 2 wheelers, hybrid electric vehicles and electric cars due to their prolonged cycle endurance, superior energy density and high power output[1,2]. The LIB produces heat during discharging and charging processes through a sequence of chemical reactions[3,4]. If heat is not drained properly, it will lead to battery temperature increment, which might expedite the ageing process of the battery. If the temperature persists in increasing it may also lead to thermal runaway[5,6]. The ideal operating condition is 5^0C temperature difference between cells and atmosphere and battery temperature between 15^0C to 50^0C[7]. So the advancement of novel battery pack cooling systems in electric vehicles is a critical necessity that must be addressed[8].

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Phase Change Material (PCM) cooling, liquid cooling, and air cooling are the main methods used to cool batteries[9].

Because air cooling is inexpensive and easy to use, it has been used extensively. The ventilation tunnel's construction and air flow direction are the primary subjects of air cooling research[10-13]. Park used numerical simulation to examine the thermal performance of various air ducts while maintaining the original stacked multiple battery cell arrangement. The suggested pressure relief and tapered manifolds have successfully improved cooling performance and satisfied cooling specifications by changing the battery box's inlet wind orientation[14,15].

The high heat transfer coefficient and quick response time of liquid cooling have garnered a lot of interest. The two primary areas of study in liquid cooling are flow structure and cooling medium[16-18]. The cooling capabilities of air cooled and liquid cooled were compared by Pesaran *et al.*, The findings showed that while air cooling can be used to cool HEV batteries, it is unable to satisfy EV needs. Air cooling is thought to be inferior to battery thermal management systems that use coolant media such as acetone, ethanol, water, and oil[19]. A series of orthogonal tests were carried out by Han *et al.* to investigate the weight coefficient of affecting parameters, such as coolant flow rate, number of channel, and cooling channel width and height[20].

PCM is often used in thermal control because it has a high phase change enthalpy and minimal temperature variation[21]. It can also improve the uniformity of surface temperature. Al-hallaj and Selman drained a 100Ah battery in an approximate adiabatic environment after applying PCM to battery TM for the first time. They discovered that using PCM reduced battery temperature by roughly 8^{0}C compared to using natural cooling[22].

This study presents an experimental evaluation of a 128-cell lithium-ion battery pack, rated at 3.7V and 2.6Ah, equipped with a circular pulsating heat pipe as shown in Table 1. The study investigates the performance of base fluid of water-ethanol mixture, tested at different filling ratios. The water and ethanol mixture volume concentration is adjusted throughout the experiments. To enhance thermal conductivity, GNPS nanoparticles are added with their mass concentration varied as well.

Table 1. Experimental setup specifications

Component	Specification
Battery Type	Cylindrical Lithium-ion
Battery Configuration	128 cells (12 rows × 7 columns × 2 sets)
Battery Rating	3.7 V, 2.6 Ah per cell
Heat Pipe Type	Circular Pulsating Heat Pipe (PHP)
PHP Material	Copper tubing
PHP Dimensions	OD: 3 mm, ID: 2.5 mm, Length: 749 mm

2.0 Methods

2.1 Selection and Preparation of Nanofluids

The water with ethanol solution base fluid was prepared by a volume ratio of 40:60. GNPS nanoparticles were selected based on thermal conductivity as shown in Table 2 and was added by mass concentration of 0.1% to this base fluid.



Figure 1. Ultrasonicator used for nanofluid preparation.

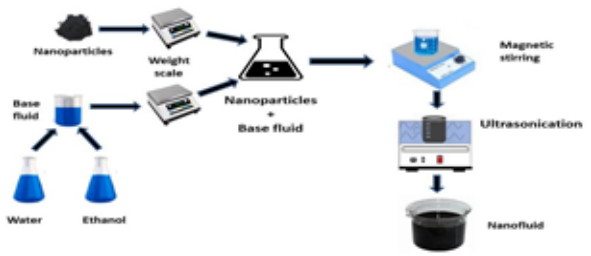


Figure 2. Flow process for preparation of nanofluids.

Table 2. Nanoparticles and their thermal conductivity

Nanoparticles	Thermal conductivity
Graphene Nanoplatelets (GNP)	3000–5000 W/m·K
Multi-Walled Carbon Nanotubes (MWCNTs)	~2000–3000 W/m·K
Copper Oxide (CuO)	~75 W/m·K,
Aluminum Oxide (Al_2O_3)	~30 W/m·K

Table 3. GPN's properties

Property	Value / Description
Thermal Conductivity	~3000–5000 W/m·K
Specific Surface Area	~500–750 m^2/g
Particle Thickness	1–10 nm
Lateral Size	1–5 µm

To enhance stability and dispersion, the mixture underwent magnetic stirring for 30 minutes, followed by 30 minutes of ultrasonication as shown in Figure 1. This procedure as shown in Figure 2 was repeated for different volume ratios of water-ethanol, as well as varying mass percentages of GNPS nanoparticles. The properties of GNP'S is shown in Table 3.

2.2 Design and Fabrication of PHP

The battery pack and circular-shaped pulsating heat pipe made from copper tubing are depicted in Figure 3. Two sets of Pulsating Heat Pipes were utilized for the purpose of cooling the battery. Each pipe features an OD of 3 mm and ID of 2.5 mm. The length of heat pipe is

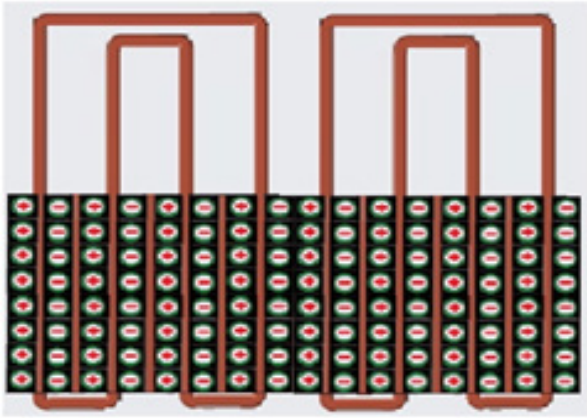


Figure 3. Schematic diagram of PHP and battery pack.

749 mm, with 300 mm condenser section and 600 mm evaporator section. The spacing between adjacent tubes is 42 mm and the overall width of the PHP is 138 mm. For the battery a commercial cylindrical lithium-ion cell was chosen, which measures 65 mm in length and 18 mm in diameter.

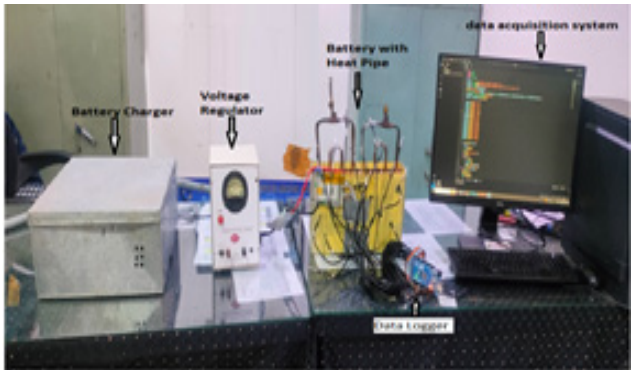
The cell has an output voltage of 3.7V and a capacity of 2.6 Ah. The battery pack consists of a total of 128 cells, arranged in a configuration of 12 rows and 7 columns across 2 sets.

2.3 Experimental Setup

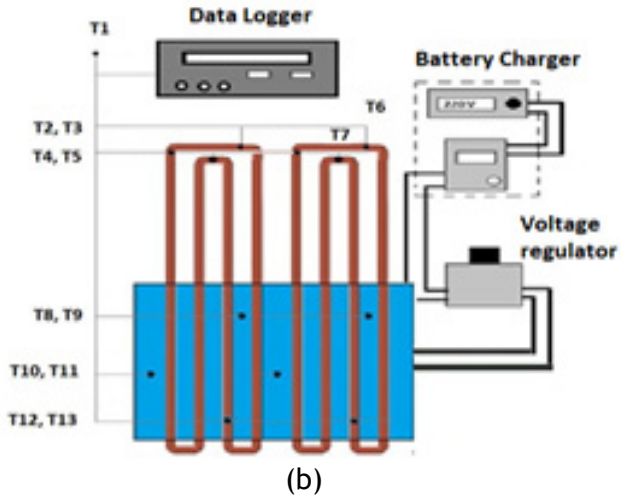
The experimental setup, as illustrated in Figure 4, includes a battery pack with circular pulsating heat pipe, a voltage regulator, battery charger, and a data acquisition system for temperature monitoring. 0.1 mm diameter T-type thermocouples were employed to measure the temperature variation. Thermocouple T1 was used to measure the ambient temperature.

Table 4. Variables and their levels

	Level 1	Level 2	Level 3
Charging C-rate	1 C	1.5 C	2 C
Filling ratios (FR)	40%	50%	60%
volume ratio (VR)	40:60	50:50	60:40
GNP's mass concentration	0.1%	0.2-0.9%	1%



(a)



(b)

Figure 4. **(a)**Actual experimental setup and **(b)** Schematic diagram of the experimental setup.

Six thermocouples (T2–T6) were positioned in the condenser section, while another six thermocouples (T8–T13) were placed in the evaporator section and across the battery pack. All temperature data were recorded by a data logger. The variable parameters are shown in Table 4.

3.0 Results and Discussion

Figure 5 illustrates the temperature profile of a heat pipe during a 1C charging test with a 0% filling ratio. Over time, the temperature within the battery pack increased, eventually reaching 99.1°C, which is substantially higher than the surrounding ambient temperature. The temperature of the condenser varied as well. The majority of the heat produced was transmitted via the heat pipe by conduction when there was no working fluid present.

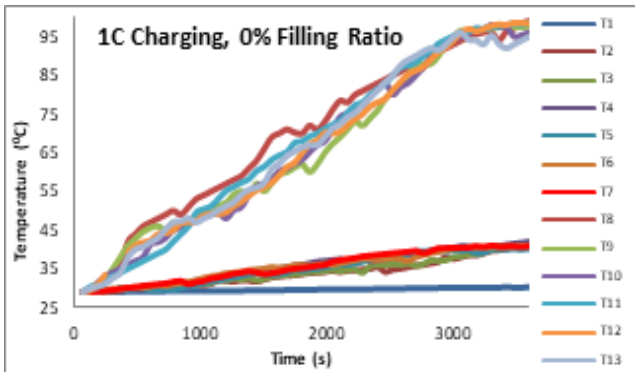


Figure 5. Temperature variations vs time for 1C charging and 0% filling ratio.

Convection and radiation were used to dissipate the heat at the condenser region.

Figures 6 and Figure 7 illustrates the temperature profile during 1.5C and 2C charging with 0% filling ratio.

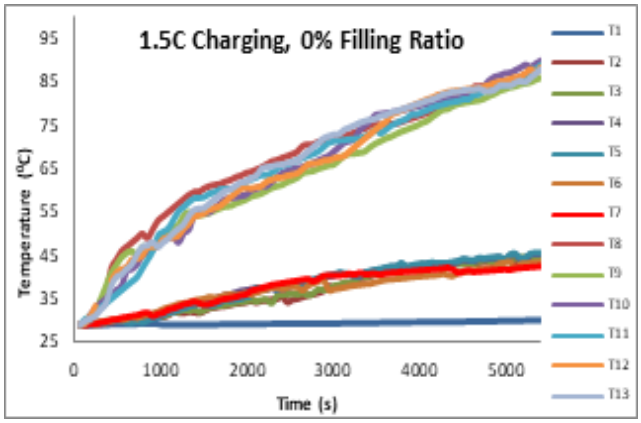


Figure 6. Temperature variations vs time for 1.5C charging and 0% filling ratio.

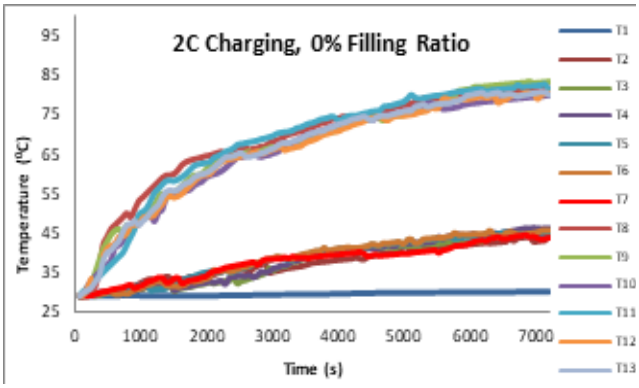


Figure 7. Temperature variations vs. time for 2C charging and 0% filling ratio.

During 1.5C and 2C charging the maximum battery temperature is 90°C and 83.4°C. The temperature of the condenser section increases as the amount of heat dissipated is increased

Figures 8 Figure 9 and Figure 10 illustrates the temperatures variation of HP with filling ratio of 40%, 50% and 60% and volume ratios of water-ethanol combination of 40:60, 50:50 and 60:40. Figure 8 demonstrates that when a mixture of water and ethanol is introduced at a 40% filling ratio, the temperature in the HP increases.

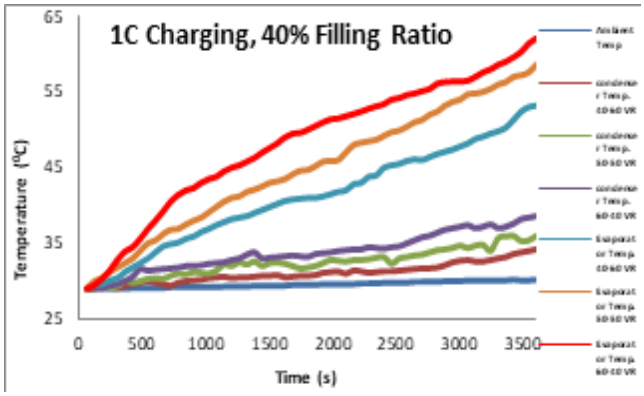


Figure 8. Temperature variations vs. time for 1C charging and 40% filling ratio.

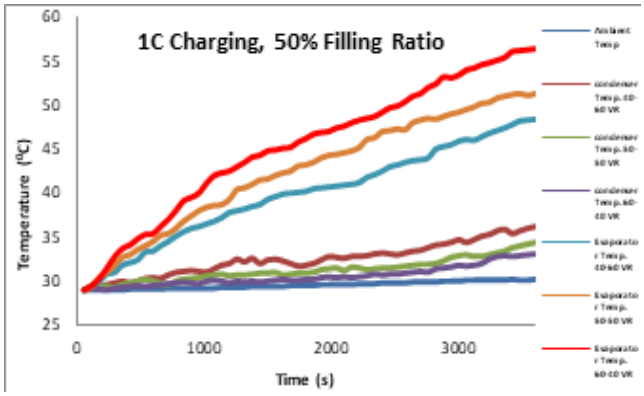


Figure 9. Temperature variations vs. time for 1C charging and 50% filling ratio.

This is in contrast to the temperature in an empty HP which remains lower. Initially, the base fluid does not reach its boiling point due to an insufficient amount of heat being generated. However, as time progresses, the heat produced causes the formation of bubbles in the evaporator region, leading to oscillating movements

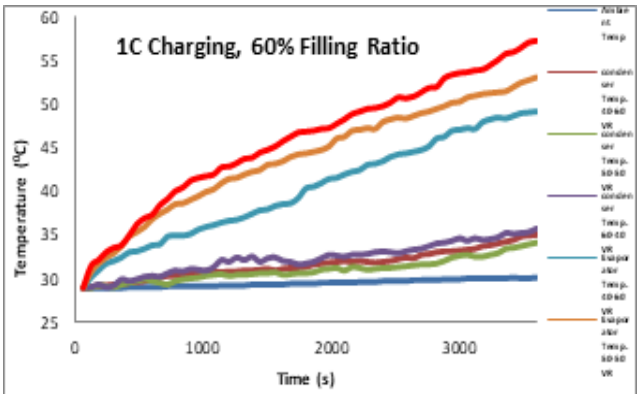


Figure 10. Temperature variations vs. time for 1C charging and 60% filling ratio.

within the HP. This process enhances the overall performance as time continues. Thus, the temperature within the battery pack decreases from 99.1°C to 53.2°C, 58.6°C, and 62.1°C.

Figure 9 presents a comparison of the temperature profiles of a heat pipe charged with water-ethanol mixtures at various volume ratios with a 50% filling ratio.

It is clear that the 40–60 volume ratio of water-ethanol mixture performs better than the other mixtures. As the ethanol content increases, the temperature of the battery pack decreases. This improvement in overall performance is attributed to the sustained temperature fluctuations in the condenser area. For volume ratios of 60:40, 50:50, and 40:60, respectively, the evaporator recorded the highest temperatures of 48.4°C, 51.3°C, and 56.4°C.

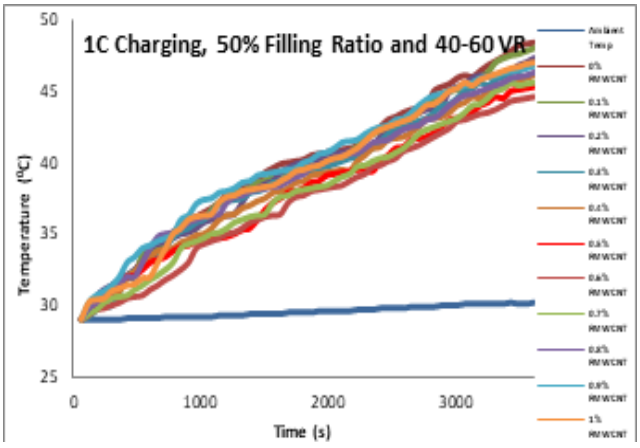


Figure 11. Temperature variations vs time for 1C charging, 60% filling ratio and 40-60 VR.

The behavior of water-ethanol mixtures at various volume ratios and a 60% filling ratio is shown in Figure 10. It has been noted that the battery pack's temperature rises in tandem with an increase in filling ratio. A higher filling ratio affects bubble formation in the evaporator region, which in turn disrupts the motion within the HP. This disturbance leads to inefficient heat transfer rate from the evaporator section to the condenser section, which causes the battery pack temperature to increase. Compared to the 50% filling ratio, the temperature rises to 49.2°C, 53.1°C, and 57.3°C from the previous values of 48.4°C, 51.3°C, and 56.4°C.

It is observed that both filling ratio and volume ratio greatly influence the battery transient temperature. Under optimal conditions with a 50% filling ratio and a 40:60 volume ratio the lowest temperature of 48.4°C is recorded.

Figure 11 shows the average evaporator temperature over time of an HP filled with 50% filling ratio and a 40:60 volume ratio and mass concentrations of 0.1% to 1% by weight of GNPS nanofluids. It is observed that on addition of GNPS nanomaterials the average evaporator temperature reduces which indicates an improvement in heat transfer efficiency. The average temperature of the evaporator stays below 50°C for all tested concentrations of GNPS nanofluids. At a mass concentration of 0.6% the lowest measured average temperature is 44.6°C, which is 3.8°C lower than the base fluid mixture. The degradation of nucleate boiling brought on by the deposition of GNPSs is mostly responsible for the higher evaporator temperatures that occur when the concentration is increased from 0.7% to 1%.

4.0 Conclusion

In this study, a circular heat pipe is tested experimentally under 2C, 1.5C and 1C charging conditions using a mixture of water and ethanol as the base fluid. The volume ratios of water to ethanol were varied at 40:60, 50:50 and 60:40 with corresponding filling ratios of 40%, 50% and 60%. The results showed that the water-ethanol mixture with a 40% filling ratio outperformed the 0% filling ratio in terms of heat transfer performance for the pulsating heat pipe. Specifically, the temperature of the battery pack decreased from 99.1°C to 53.2°C with the 40% filling ratio. Further reductions in temperature were observed as the volume ratio changed from 60:40 to 50:50 and 40:60, the temperature dropped to 58.6°C and 62.1°C, respectively. Both filling ratio and volume ratio had a significant impact on the heat pipe performance. When the filling ratio was increased to 50%, the temperature of the battery pack further decreased, reaching a minimum of 48.4°C, 51.3°C, and 56.4°C for the different volume ratios. The lowest temperature observed was 48.4°C, achieved with a 50% filling ratio and a 40-60 volume ratio. Compared to the 0% filling ratio, this represents a temperature reduction of 50.7°C

GNPS nanofluids were prepared by mixing a base fluid of water-ethanol at 40:60 volume ratio and the mass concentrations of the GNPS nanofluids were varied between 0.1% and 1% by weight. At 50% filling ratio the results demonstrated that adding GNPS nanofluids significantly reduced both the battery pack temperature and the average evaporator temperature of the heat pipe compared to the water-ethanol mixture. As the concentration of GNPS increased from 0.1% to 0.6% the average evaporator temperature continued to decrease. However, when the concentration increased from 0.6% to 1% a rise in temperature was observed. The optimal performance was achieved at a concentration of 0.6% where the average evaporator temperature was reduced by 3.8°C compared to the base fluid mixture without nanoparticles. With this setup, the battery pack temperature of 44.6°C could be achieved. These findings suggest that using heat pipes filled with a water-ethanol mixture as the base fluid and incorporating GNPS nanofluids presents an effective cooling strategy for electric vehicle applications.

5.0 References

1. Rawat S, Kumar R. Techno-economic analysis of cooling technologies used in electric vehicle battery thermal management, Energy Storage. 2024; 103:114135. https://doi.org/10.1016/j.est.2024.114135
2. Vetter J, Novák P, Wagner M, Veit C, Möller K, Besenhard J, *et al.,* Ageing mechanisms in lithium-ion batteries. J Power Sources. 2005; 147:269-81. https://doi.org/10.1016/j.jpowsour.2005.01.006
3. Williford R, Zhang J, Viswanathan V. Effects of entropy changes in anodes and cathodes on the thermal behavior of lithium-ion batteries. J Power Sources. 2009; 189:101-7. https://doi.org/10.1016/j.jpowsour.2008.10.078

4. Saito Y. Thermal behaviors of lithium-ion batteries during high-rate pulse cycling. J Power Sources. 2005; 146:770-4. https://doi.org/10.1016/j.jpowsour.2005.03.089
5. Kong D, Chen G, Wen J, Peng R, Ping P, Du J. A novel battery thermal management system coupling with PCM and optimized controllable liquid cooling for different ambient temperatures. Eng Conv Manag. 2020; 204:112280. https://doi.org/10.1016/j.enconman.2019.112280
6. Wu W, Wang S, Wu W. A critical review of battery thermal performance and liquid-based battery thermal management. Energy Conv. Manag. 2019; 182:262-81. https://doi.org/10.1016/j.enconman.2018.12.051
7. Wang Q, Ping P, Zhao X, Chu G, Sun J, Chen C. Thermal runaway caused fire and explosion of lithium-ion battery. J Power Sources. 2012; 208:210-24. https://doi.org/10.1016/j.jpowsour.2012.02.038
8. Fan L, Khodadadi J, Pesaran A. A parametric study on thermal management of an air-cooled lithium-ion battery module for plug-in hybrid electric vehicles. J Power Sources. 2013; 238:301-12. https://doi.org/10.1016/j.jpowsour.2013.03.050
9. Williford R, Zhang J, Viswanathan V. Effects of entropy changes in anodes and cathodes on the thermal behavior of lithium-ion batteries. J Power Sources. 2009; 189:101-7. https://doi.org/10.1016/j.jpowsour.2008.10.078
10. Park H. A design of air flow configuration for cooling lithium-ion battery in hybrid electric vehicles. J Power Sources. 2013; 239:30-6. https://doi.org/10.1016/j.jpowsour.2013.03.102
11. Yates M, Akrami M, Javadi A. Analysing the performance of liquid cooling designs in cylindrical lithium-ion batteries. J Energy Storage. 2021; 33:55-63. https://doi.org/10.1016/j.est.2019.100913
12. Saw L, Ye Y, Tay A, Chong W, Kuan S, Yew M. Computational fluid dynamic and thermal analysis of lithium-ion battery pack with air cooling. Appl Energy. 2016; 177:783-92. https://doi.org/10.1016/j.apenergy.2016.05.122
13. E J, Meng Y, Chen J, Zhu H, Deng Y, Zhu Y, *et al.* Effects of the different air cooling strategies on cooling performance of a lithium-ion battery module with baffle. Appl Therm Eng. 2018; 144:231-41. https://doi.org/10.1016/j.applthermaleng.2018.08.064
14. Pesaran A. Battery thermal models for hybrid vehicle simulations. J Power Sources. 2002; 110:377-82. https://doi.org/10.1016/S0378-7753(02)00200-8
15. Hu C, Li H, Wang Y, Hu X, Tang D. Experimental and numerical investigations of lithium-ion battery thermal management using flat heat pipe and phase change material. J Energy Storage. 2022; 55:105743. https://doi.org/10.1016/j.est.2022.105743
16. Huo Y, Rao Z, Liu X. Investigation of power battery thermal management by using mini-channel cold plate. Energy Convers Manag. 2015; 89:387-95. https://doi.org/10.1016/j.enconman.2014.10.015
17. Malik M, Rosen M, Dincer I. Thermal and electrical performance evaluations of series connected Li-ion batteries in a pack with liquid cooling. Appl Therm Eng. 2018; 129:472-81. https://doi.org/10.1016/j.applthermaleng.2017.10.029
18. Tang A, Shan C, Yuan X, Li J, Lou L. Optimization design and numerical study on water cooling structure for power lithium battery pack. Appl Therm Eng. 2019; 159. https://doi.org/10.1016/j.applthermaleng.2019.113760
19. Pesaran A, Keyser M, Burch S. An approach for designing thermal management systems for electric and hybrid vehicle battery packs. In: Proc. Fourth vehicle thermal management systems conference and exhibition; 1999.
20. E J, Han D, Qiu A, Chen J, Zhao X, Zuo W, *et al.*, Orthogonal experimental design of liquid-cooling structure on the cooling effect of a liquid-cooled battery thermal management system. Appl Therm Eng. 2018; 132:508-20. https://doi.org/10.1016/j.applthermaleng.2017.12.115
21. Khan M, Bhuiyan Z, Ahmed H. Investigation of heat transfer of a building wall in the presence of phase change material (PCM). Energy Built Environ. 2020; 1(2):199-206. https://doi.org/10.1016/j.enbenv.2020.01.002
22. Al-Hallaj H, Selman J. A novel thermal management system for electric vehicle batteries using phase-change material. J Electrochem Soc. 2000; 147(9):3231-7. https://doi.org/10.1149/1.1393888

Abbreviations

EVs	-	Electric Vehicles
PHP	-	Pulsating Heat Pipe
FR	-	Filling Ratio
VR	-	Volume Ratio