Volume 5 Issue 1 (March 2025)
DOI 10.24191/jaeds.v5i1.97
eISSN 2805-5756

Journal of Applied Engineering Design & Simulation

# Experimental Investigation of Hydrogel-Based Passive Cooling for Battery Thermal Management in EV Applications

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## ABSTRACT

The growing adoption of electric vehicles (EVs) has necessitated the efficient and energy-saving battery thermal management systems (BTMS) in the market. The operation of lithium-ion batteries creates a lot of heat, and prolonged exposure leads to performance degradation and raises a safety risk. Although active cooling techniques work, they take additional energy and decrease driving distance. This work investigates the performance of a passive cooling technique based on hydrogel layers for 12V prismatic $LiFePO_4$ batteries. A test rig was built to simulate and measure two scenarios: air-cooled and hydrogels to air-cooled. The hydrogel-based system was shown to bring down the maximum temperature of the battery to 30.0°C versus a temperature of 35.8°C observed in the absence of hydrogel, suggesting a better thermal regulation without any additional power consumption.

**Keywords**: Electric Vehicle; battery thermal management system; $LiFePO_4$ battery; hydrogel

***Nomenclature (Greek symbols towards the end)***

| | |
|---|---|
| $V$ | voltage |
| $Ah$ | capacity battery |
| $LiFePO_4$ | lithium iron phosphate |
| $\dot{Q}_{total}$ | heat transfer |
| $R_{conduction}$ | conductive thermal resistance |
| $R_{convection}$ | convective thermal resistance |
| $h$ | heat transfer coefficient |
| $Nu$ | nusselt number |
| $Ra$ | rayleigh number |
| $Pr$ | prandtl number |
| $Gr$ | grashof number |
| $\beta$ | volumetric thermal expansion coefficient |

***Abbreviations***

| | |
|---|---|
| *EV* | electrical vehicles |
| *ICE* | internal combustion engine |
| *BTMS* | battery thermal management system |
| *TMS* | thermal management systems |
| *PCM* | phase change material |
| *EER* | energy efficiency ratio |
| *SoC* | state of charge |

## 1.0 INTRODUCTION

Electric vehicles (EVs) are making significant inroads as a legitimate alternative to internal combustion engine (ICE) vehicles, and the global automotive landscape is shifting as a result. By investing heavily in EV research and development, manufacturers are innovating to achieve on-par or better performance of EVs compared to their gas-powered counterparts. Malaysia has also set aggressive targets to fast-track EV adoption, with electric vehicles expected to make up 20% of vehicles on the road by 2025 [1]. This commitment is further strengthened through strategic initiatives such as the Low Carbon Mobility Blueprint and the National Energy Transition Roadmap 2021-2040, which prescribe policies to accommodate the electrification of the transport sector [1].

Received on 09.03.2025
Accepted on 26.03.2025
Published on 30.03.2025

Battery thermal management is one of the main challenges faced by the mass introduction of EVs, despite the developments. The total amount of energy requirement in a lithium-ion battery pack causes a significant amount of heat to be released due to the high speed of the electrochemical reaction. If the temperature of the battery exceeds the optimal operating conditions, it can result in poor performance, reduced capacity, and, in some cases, thermal runaway, which can lead to catastrophic failure. To address these risks, EV makers like Tesla have integrated active cooling Battery Thermal Management Systems (BTMS) into their battery packs. While effective, those active cooling systems use extra power, sapping energy from the battery itself and diminishing the vehicle's driving range. Acknowledging these constraints, significant research has focused on developing other thermal management strategies that minimize performance and energy costs.

BTMS can be broadly classified as active cooling or passive cooling. Forced conduction and convection to manage battery temperature are achieved through mechanical components like pumps and fans in active cooling systems. However, this process uses an additional power source, thus adding to the power consumption. Passive cooling systems are very different from their active counterparts, with passive cooling systems relying entirely on heat transfer mechanisms like conduction and convection. It helps the system to operate independently without requiring any input from green energy sources. Therefore, as a passive cooling strategy, researchers are identifying new materials and designs that can improve their effectiveness, potentially providing lighter, safer, and cooler solutions for EV batteries. Therefore, the objective of this study is to experimentally investigate the effectiveness of hydrogel layers as a passive cooling solution for 12V prismatic $LiFePO_4$ batteries, by comparing their thermal performance under natural air cooling with and without hydrogel integration.

### 1.1 Passive cooling techniques in Battery Thermal Management Systems (BTMS)

Passive cooling has emerged as a feasible way to improve the thermal management of lithium-ion batteries in electric vehicles, according to recent work. Studies show that specific passive cooling techniques give significant reductions in battery temperature. The maximum temperature of the battery pack decreased by 1°C, and the temperature differential was reduced by 2°C, as reported by S. Zhang et al. and H. Jannesari et al. [2-3], which showed improvement of thermal performance and provided a reference for battery thermal management systems optimization. Numerous passive cooling methods, such as PCMs, heat pipes, and hydrogel layers, have been studied to solve the risk of thermal runaway and optimize lithium-ion battery operation.

Heat pipes are an excellent passive cooling technology that utilizes latent heat to transfer thermal energy from hotter areas toward cooler regions, resulting in more uniform temperature distribution within the battery pack. Likewise, phase change materials (PCMs) have been studied as a passive way of providing cooling as they can absorb and release a large amount of latent heat during phase transitions, thus, stabilizing the temperature variations of the battery. The majority of heat sinks are made from pure aluminum because it possesses a very high thermal conductivity and is able to dissipate excess heat and maintain thermal stability extremely well. According to the experimental results of L. J. Zheng and H. W. Kang, a passive evaporative cooling heat sink could reach a temperature of 150°C on the hot side and 69.3°C on the cold side at a discharging rate of 2C, indicating a remarkable capacity to maintain the battery at an appropriate temperature [4]. Furthermore, a study by Watcharajinda et al. showed that an open pond heat sink achieves an energy efficiency ratio (EER) of 4.1, outperforming the traditional air-cooled systems segment in some cases as reported in [5]. In a separate but related study, Gonzalez-Valle et al. measured the heat sink of a water-cooled system and found that it is able to keep the temperature constant over 10 seconds at 54°C on the surface of the CPU under full load [6].

Even though passive cooling technologies are advancing promisingly, it is still limited, particulary under high thermal loads such as fast charging and high-power discharging where the heat generated exceeds the dissipation capacity of passive systems. Of these many passive cooling approaches, phase change materials (PCMs) have gained great attention owing to their capacity to absorb and store substantial heat at a vast temperature range during the transition from solid to liquid and subsequently releases this stored heat upon going from liquid to solid, keeping the temperature of batteries in the best operating range [7–9]. Colonics is a popular method of cleansing with a lot of techniques that claim good results. A study from Cao et al. indicated an effective control of the velocity and inlet temperature of the cooling fluid when applying a liquid cooling strategy with incorporated PCM, thus achieving improved thermal performance of the battery pack while reducing the excess power consumption in the cooling system [10]. A systematic review by Ling et al. showcased the benefits of PCM-based thermal management systems, which include high latent heat storage, improved thermal conductivity, and cost efficiency [11]. Passive cooling methods have been shown to be effective in terms of temperature management over sizable temperature ranges; however, adjustment of such methods for high-energy-density lithium-ion batteries still poses challenges in the battery market. One potential avenue that has been receiving more attention recently is the addition of hydrogel layers, which serve as a passive cooling solution. With remarkable water absorption and evaporative cooling abilities, hydrogels serve as a new way to achieve prolonged heat dissipation without extra energy input. Their high thermal responsiveness opens up new opportunities for hydrogel-based cooling systems which can be studied more extensively for applications such as battery thermal management, where traditional passive cooling systems may fall short.

### 1.2 Hydrogel-based passive cooling

Hydrogels are three-dimensional cross-linked hydrophilic polymer networks that can absorb and retain large amount of water. The excellent thermal regulation via evaporative cooling due to their porous structure and high-water content enables the hydrogels to keep their temperature low and stable or unchanged, which is good for passive thermal management applications. When the hydrogel absorbs water, it gradually evaporates when exposed to heat, removing heat from the surface in the process. The existing passive cooling approaches are inadequate, thus it is imperative to adopt layers with hydrogels for efficient thermal management of electric vehicle (EV) batteries.

Liu et al. showed that the hydrogel-based passive cooling system can regulate Li-ion battery pack temperatures effectively during fast charging and high-power discharging. They found that the hydrogel layer application decreased the maximum temperature gradient of the battery pack concerning a conventional air-cooling system by ~8°C [12]. Furthermore, the hydrogel-based cooling mechanism was constructed to achieve a better temperature uniformity of the battery pack with a max-temperature difference of 1.4°C [13]. This is a substantial improvement compared to conventional air-cooled systems, which often struggle to maintain a consistent battery pack temperature. The performance of hydrogel-based cooling systems is significantly influenced by external environmental conditions, particularly temperature and relative humidity. According to L.E. Helseth, even a modest increase of 10 °C in ambient temperature and 10% in relative humidity can notably affect the thermal response of the hydrogel system [14]. Additionally, fluctuations in current flow within the battery contribute to temperature variations, which in turn alter the local humidity levels surrounding the hydrogel layer.

A. M. Coclite et al. demonstrated that at an ambient temperature of 23 °C, the hydrogel exhibited a gradual swelling behaviour, with water absorption increasing by approximately 35% as the relative humidity rose to 95% [15]. In terms of long-term performance, Zhouzhou et al. conducted degradation studies on hydrogels and reported that significant structural degradation occurred after approximately 2000 minutes of operation [16]. Furthermore, hydrogel application has also been explored in cylindrical battery configurations. S. Mehryan et al. investigated the use of hydrogel wrapping around 18650-type lithium-ion batteries. Their findings indicated improved thermal regulation through direct hydrogel contact with the battery surface, suggesting its applicability across various battery geometries [17].

Peihua Y. et al. further improved the study by investigating the use of hydrogel-based materials in the passive thermal management of Li-ion batteries. Their work was brought to attention due to the hygroscopic nature of hydrogels allowing them to rapidly dissipate heat under high-temperature conditions while simultaneously providing the rehydration and recovery of cooling capacity upon a drop in temperature [18]. The ability of hydrogels to self-regenerate could also increase the long-term effectiveness of hydrogel-based cooling systems, presenting an attractive solution for effective heat management in electric vehicle (EV) battery packs.

Most of the research to date has been based on the ability of the hydrogel to take up moisture from ambient humidity. Nonetheless, the application of hydrogel for regulating heat in BTMSs has been poorly investigated. Addressing this gap, the present study investigates hydrogels for EV battery cooling, utilizing water uptake characteristics to maximize thermal management. A water reservoir can be integrated into the hydrogel-based passive cooling system to prolong the evaporative cooling effect and achieve prolonged heat dissipation, further enhancing the overall thermal management performance. Figure 2 shows the placement of hydrogel layer with water conduit on battery cell. This could provide a sustainable and energy-efficient solution compared to traditional cooling methods and shed light on future potential strategies to enhance EV battery safety and longevity.

## 2.0 METHODOLOGY

### 2.1 Experimental setup and hydrogel-based passive cooling mechanism

This experiment used four prismatic $LiFePO_4$ batteries measuring 143 mm × 145 mm × 27 mm with a nominal capacity of 38 Ah. The specifications of prismatic cells are given in Table 1. Specifically, the incorporation of a hydrogel enables passive cooling through thermal absorption and as a water channel to induce moisture transfer and retention for enhanced thermal management of the battery. The hydrogel effectively absorbs and dissipates heat generated during battery operation.

The proposed passive cooling system consisted of several components, with the hydrogel layer serving as the core element. The hydrogel is placed in direct contact with the battery surface to enhance heat transfer. As the battery operates and releases heat, the hydrogel absorbs this thermal energy. Part of the absorbed heat is stored as **sensible heat**, which increases the hydrogel's temperature, while another portion is used as **latent heat** to facilitate the **evaporation of water within the hydrogel** where a phase change process that enables effective cooling without external energy input. To sustain this evaporative effect, a water reservoir is included in the system to periodically rehydrate the hydrogel, preventing it from drying out. This setup maintains consistent cooling performance **throughout the 30-minute testing period**, ensuring stable thermal regulation during battery operation. The properties of the hydrogel material used in the experiment are shown in Table 2.

**Table 1:** Specification of the $LiFePO_4$ battery

| Items | Specification |
|---|---|
| Cathode material | $LiFePO_4$ |
| Anode material | Graphite |
| Standard capacity | 38 Ah |
| Rated voltage | 3.2 V |
| Cut-off voltage | 2.3 V |
| Dimensions | 143 mm x 145 mm x 27 mm |

**Table 2:** Properties of hydrogel cooling material

| Properties | Parameter |
|---|---|
| Thermal Conductivity | 0.605 [W/mK] |
| Heat Capacity | 4136[J/kg. K] |
| Density | 964[kg/m$^3$] |
| Thickness | 2[mm] |
| Width | 145[mm] |
| Length | 200[mm] |

## 2.2 Experimental system and procedures

The setup contains a 12V battery system comprising four series-connected $LiFePO_4$ batteries with a 1.5-mm copper busbar. The battery pack serves as the primary energy storage component in the system. The 12.8V/14.4V Battery Management System (BMS) is equipped in the system which prevents overcharging, undercharging, and any voltage imbalance between individual battery cells, ensuring the safe operation and health of the battery. The BMS also monitors the State of Charge (SoC) and temperature for optimal performance of the battery. Figure 1 is the schematic diagram for the HX-4s-F 100A BMS, based on 4s configuration.

The energy stored in the battery pack is passed through the BMS and into an inverter that converts direct current (DC) to alternating current (AC) during the discharging process. This conversion is necessary to drive loads like the system diagram's spotlight load. To improve safety and facilitate real-time tracking, we placed all the components inside a transparent acrylic box, making it easy for us to check on fire hazards.

For temperature monitoring, a K-type thermocouple is placed at the center of each battery and connected to a multi-channel temperature data recorder. This system continuously records the battery temperature throughout the experiment, providing essential data for thermal analysis. A hydrogel layer is placed between the batteries to enhance cooling efficiency, as shown in Figure 2. The hydrogel, composed of water-soluble polymers and paraben, functions as a thermal buffer by absorbing and dissipating excess heat. A water conduit made of cotton is integrated to maintain hydrogel hydration over time, allowing for detailed investigation into its role in enhancing passive cooling efficiency.

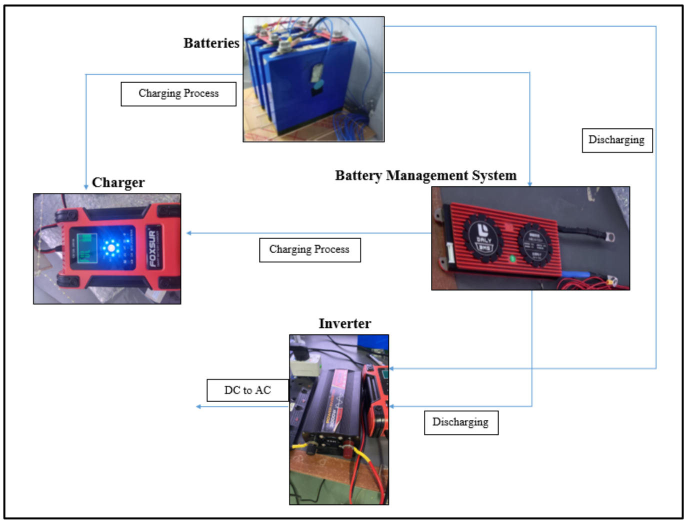
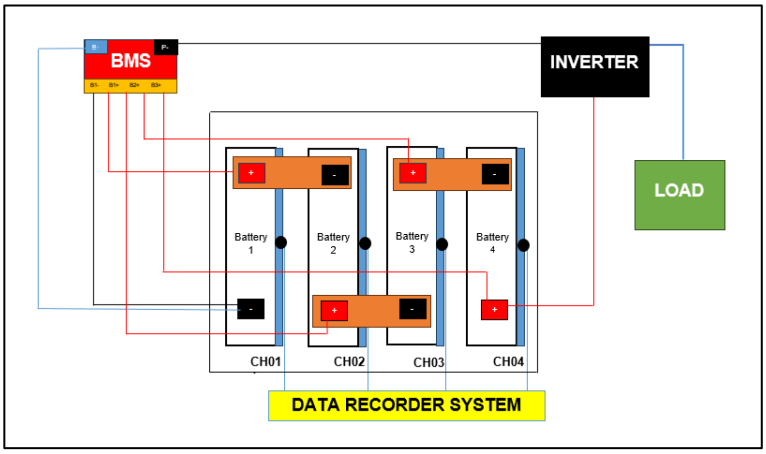
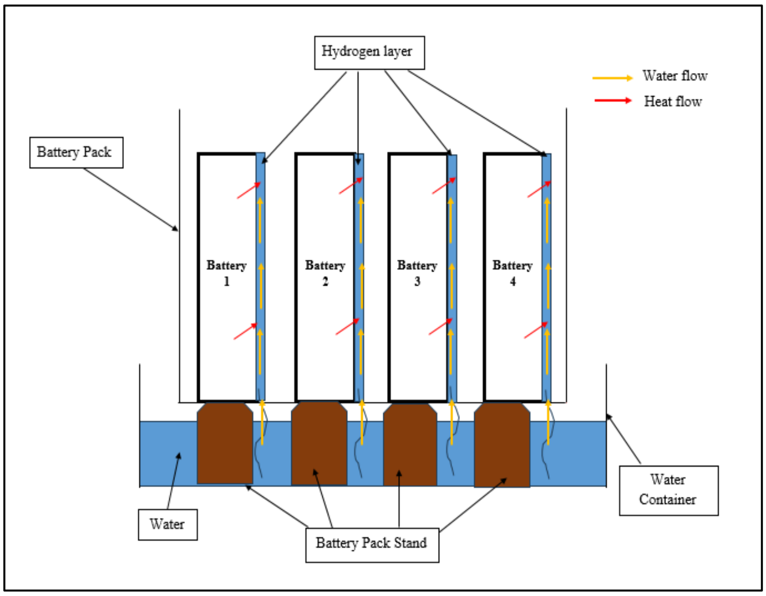


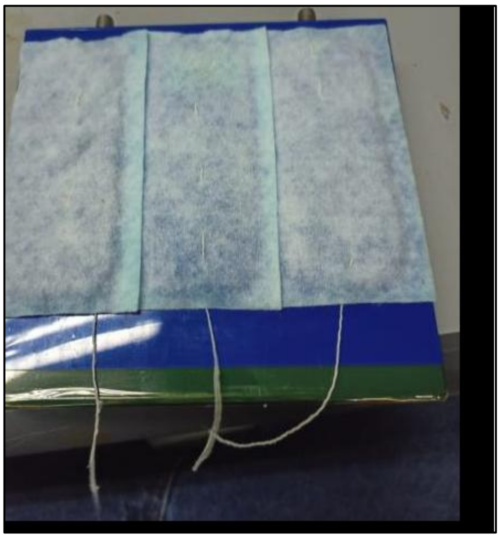

**Figure 1.** Schematic Diagram of Hydrogel Layers Passive Cooling Experiment




(a)




(b)



(c)

**Figure 2.** Schematic diagram of (a) Hydrogel layer passive cooling system circuit diagram, (b) Batteries and hydrogel layer configuration, (c) Placement of hydrogel layer with water conduit on battery cell.

The battery system is first charged to a maximum state of charge at a 1C charge rate under natural air-cooling without the use of a hydrogel sheet. The battery is then fully charged and connected to a 3000W inverter, where 12V DC is converted to 240V AC to run the given load. In this case, a 200W bulb is used as a load at a 2C rate for discharge purposes. The battery temperature is captured every 30 seconds for 30 minutes during the discharging process to characterize thermal behaviour under these conditions.

To further assess the ability of the hydrogel layer to function as a passive means of cooling, it is sandwiched on one side of the battery, and a test runs under identical conditions as the first natural air test. It is then repeated three times to get an average temperature reading for more reliable results. This approach allows for a consistent comparison between the two cooling strategies under controlled ambient temperature conditions.

### 2.3 Heat transfer analysis

In this experiment, the heat generated from the batteries is dissipated by the conduction process as it passes through hydrogel and to the air by the natural convection process. The total heat transfer rate can be determined using the Thermal Resistance Network in series as shown in Figure 3.

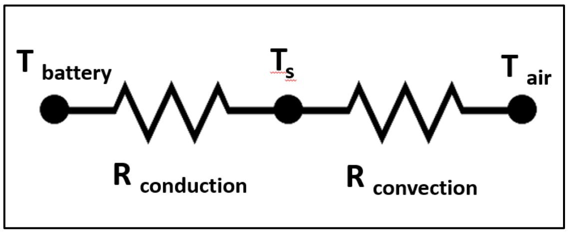



**Figure 3.** Thermal resistance network

The equation of total heat transfer can be derived from the thermal resistance network as shown in Equation (1).

$$\dot{Q}_{total} = \frac{T_{battery} - T_{air}}{R_{conduction} + R_{convection}} \quad (1)$$

By considering that this study intends to investigate the effect of the hydrogel, therefore the heat transfer analysis focuses mainly on the direction of the hydrogel layer. The conductive thermal resistance, $R_{conduction}$, and convective thermal resistance, $R_{convection}$, can be determined using Equation (2) and Equation (3) below.

$$R_{conduction} = \frac{L}{kA} \quad (2)$$

$$R_{convection} = \frac{1}{hA} \quad (3)$$

where $L$ is the thickness of the hydrogel layer, $k$ is the thermal conductivity of hydrogel, $A$ is the effective surface area, and $h$ is the heat transfer coefficient. The heat transfer coefficient, $h$, can be determined using Equation (4), where $L_C$ is the characteristic length of a hydrogel.

$$h = \frac{Nu \times k}{L_C} \quad (4)$$

The Nusselt number for the natural convection of vertical plate [19] can be calculated using Equation (5).

$$Nu = \left( 0.825 + \frac{0.387 \cdot Ra^{1/6}}{\left(1 + \left(\frac{0.492}{Pr}\right)^{9/16}\right)^{8/27}} \right)^2 \quad (5)$$

where $Pr$ is the Prandtl number and $Ra$ is the Rayleigh number that can be calculated using Equation (6).

$$Ra = Gr \cdot Pr \tag{6}$$

Grashof number, $Gr$, can be calculated using Equation (7) as shown below.

$$Gr = \frac{g \cdot \beta \, (T_s - T_\infty) \cdot {L_c}^3}{v^2} \tag{7}$$

where $g$ is the acceleration of gravity, $v$ is kinematic viscosity of ambient air, and $\beta$ is volumetric thermal expansion coefficient which can be determined using Equation (8) below.

$$\beta = \frac{1}{T_{film}} = \frac{1}{\frac{T_s + T_\infty}{2}} \tag{8}$$

## 3.0 RESULTS AND DISCUSSION

The experimental results indicate the potential of the hydrogel-based passive cooling system to address the thermal issues in high-power lithium-ion batteries. The recorded data indicate that the temperature of each cell increased uniformly over time, suggesting continuous heat generation during operation. A maximum temperature of 35.8 °C was observed under natural air cooling, as shown in Figure 4. By implementing the hydrogel-based cooling system, the maximum temperature of the battery dropped to 30.0 °C. The temperature rising of the total cells during hydrogel cooling is slower and consistently lower through the process of discharge, suggesting effective thermal management. As shown in the system under the end cycle, the hydrogel layer effectively ensured thermal uniformity in the battery pack, with the temperature difference between the two individual cells reduced to the ultimate gap of 6.8 °C. Hydrogel cooling systems can maintain greater uniformity of temperature profiles among the cell pairs than natural air cooling. This minimizes thermal imbalance, which is important to keep battery systems healthy and performing optimally.

Figure 4 illustrates the temperature profiles of four battery cells (CH01–CH04) under two different cooling strategies: natural air cooling (solid lines) and hydrogel-based passive cooling (dashed lines). Over the 1800-second discharge period, the cells subjected to natural air cooling exhibited a continuous rise in temperature, with the maximum temperature reaching approximately 35.8 °C. In contrast, the hydrogel-cooled batteries maintained significantly lower temperatures throughout the test, with a peak value of approximately 29.0 °C. The temperature difference between the two methods became increasingly evident over time, with the hydrogel system effectively limiting the rate of temperature increase. Notably, the maximum temperature rise under hydrogel cooling was only about 1.0 °C, compared to 6.8 °C in the natural air cooling case. The temperature differential of almost 7 °C demonstrates the efficiency of the hydrogel in cooling the battery system. Wu et al. [20] previously showed that by adopting a pure hydrogel system with a direct contact design, they were able to achieve a temperature differential of 2.5°C and 2.3°C greater than a natural air-cooled environment. This substantial reduction in thermal buildup confirms the hydrogel layer's ability to enhance heat dissipation through evaporative cooling, thereby stabilizing battery temperature during operation.

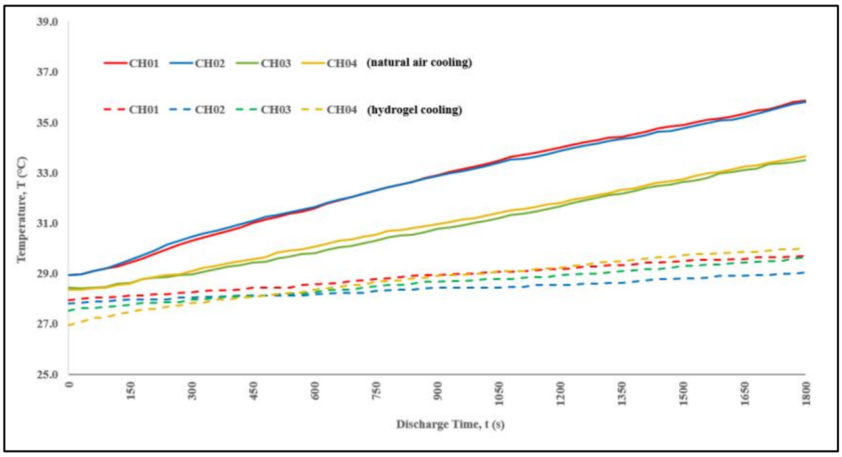



**Figure 4.** Data comparison between the average temperature of natural air cooling and hydrogel cooling method

Figure 5 highlights a clear distinction between natural cooling and cooling with hydrogel across the four channels (CH01 to CH04). Natural cooling consistently showed higher temperature differences, starting at 6.9°C in CH01 and CH02, then decreasing to 5.1°C in CH03 before slightly increasing to 5.3°C in CH04. In contrast, cooling with hydrogel exhibited significantly lower temperature differences, starting at 1.8°C in CH01 and decreasing to 1.2°C in CH02, followed by a gradual increase to 2.1°C in CH03 and 3.1°C in CH04. These results indicate that hydrogel cooling is initially more effective, achieving substantial reductions in temperature compared to natural cooling, particularly in the earlier channels. However, its efficiency appears to decline in the later channels, likely due to heat saturation or reduced thermal dissipation performance over time. Despite this, hydrogel cooling consistently outperforms natural cooling, maintaining a lower temperature difference throughout. These findings suggest that hydrogel cooling is highly effective for short-term or localized applications but may require optimization for extended or multi-stage cooling systems to maintain its superior performance.

Figure 6 displays the thermal transfer rate vs the temperature difference of two cooling types: natural and hydrogel cooling. The results showed a significant improvement in heat dissipation using the hydrogel-based cooling system as opposed to the natural cooling system. Results from the experimental studies showed the same trend as the calculated values, confirming the efficiency of hydrogel-based cooling. In contrast to the natural cooling method, which showed an almost flat trend with almost no heat transferred, the hydrogel-based cooling system showed a significant increase rate of heat transfer as the temperature difference increased.

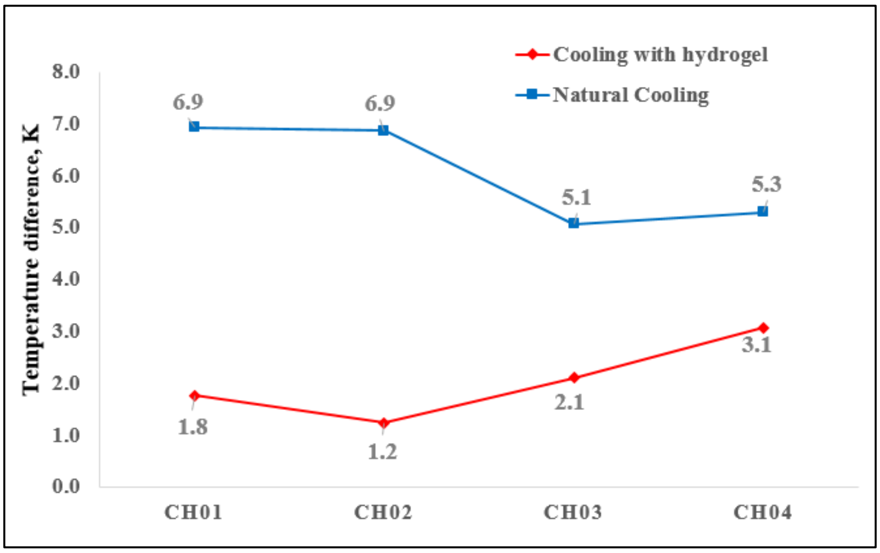



**Figure 5.** Comparison of temperature differences between natural cooling and hydrogel cooling across four battery cells channels (CH01–CH04).

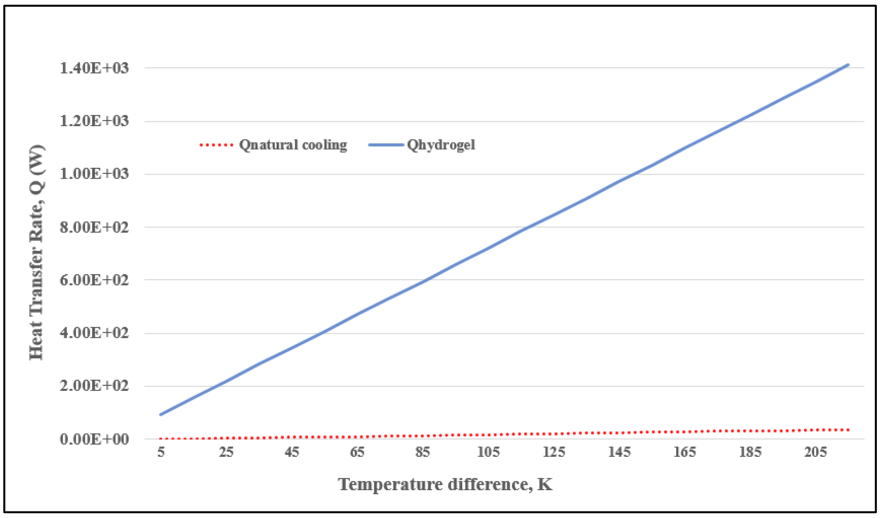



**Figure 6.** Comparison of heat transfer rate between natural cooling and hydrogel-based cooling system

This behaviour showed that the hydrogel effectively absorbs heat for battery cooling technology. To further assess how well the system performs, the heat transfer rate was considered for high battery temperature, that is, 250°C, which is the triggering temperature of thermal runaway of $LiFePO_4$ batteries [21]. The temperature difference was determined by applying heat transfer equations specific to this analysis and consisted of an ambient temperature of 300K. At the elevated temperature, the recalculated heat transfer showed that without hydrogel cooling, simple natural convective heat transfer is insufficient to prevent increased battery temperature from rising too high, risking overtemperature and even thermal runaway conditions. This passive cooling effect is further improved by the presence of the hydrogel cooling system, which permits the hydrogel to extract and dissipate heat through conduction, convection, and evaporative cooling.

These findings highlight the effectiveness of hydrogel-based passive cooling as an energy-efficient Battery Thermal Management System (BTMS). Unlike active cooling, which requires additional power consumption, hydrogel-based cooling operates passively by leveraging its high water absorption and heat dissipation properties. The ability of hydrogel cooling to regulate battery temperature and delay the onset of thermal runaway makes it a promising solution for enhancing the safety and performance of lithium-ion battery packs in electric vehicles. Future improvements in hydrogel rehydration methods could further extend its cooling efficiency, making it an even more viable approach for long-term battery thermal management.

## 4.0 CONCLUSION

In this study, the performance of a hydrogel-based passive cooling system was evaluated against natural air cooling for a 12V $LiFePO_4$ battery pack. The relative assessment examined the temperature differentials for both cooling strategies used to evaluate how effectively temperature is regulated in the corresponding battery. The experimental results demonstrated that the application of a hydrogel layer significantly improved heat dissipation from the battery surface. The maximum battery temperature recorded under hydrogel-based cooling was **30.0 °C**, with a minimal temperature variation of only **1.0 °C** across the battery surface, indicating effective temperature uniformity. Compared to natural air cooling, the hydrogel system reduced the peak temperature rise by approximately **6.8 °C**, highlighting its potential as a passive thermal management strategy. These findings suggest that the hydrogel contributes to improved thermal regulation performance without the need for active cooling mechanisms. The hydrogel-activated cooling system demonstrated effectiveness in regulating the temperature of the battery, especially increases that occurred during high discharge rates through conduction, convection, and evaporative cooling effects. The hydrogel layer reduced the risk of localized overheating and required a more even temperature distribution on the battery cells, which makes the battery pack more thermally stable and safe. The hydrogel base cooling could thus be used as a passive thermal management solution to limit limiting heat buildup, while ensuring peak battery performance. In the future, the composition of hydrogel and rehydration methods could be certainly optimized to promote the durability of the electrolyte, especially in high-energy-density batteries. These discoveries impact a more energy-efficient BTMS solution, thereby favouring the extensive use of electric-powered vehicles, along with assuring battery lifetime, security, and functioning integrity.

## ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to **Universiti Teknologi MARA (UiTM)** for providing the facilities and resources necessary for this research. Special appreciation is extended to the research team members for their invaluable technical support and insightful discussions throughout the study. This research was funded by the Geran Inisiatif Penyelidikan (GIP), (600-RMC/GIP 5/3 109/2021) from Universiti Teknologi MARA, which made this study feasible. The authors also extend their appreciation to the reviewers and editors for their constructive feedback, which has contributed to improving the quality of this manuscript.

## AUTHORS CONTRIBUTION

Muhammad Aiman Shafiq Abdul Rahman: Formal analysis, investigation, Methodology, Writing-Original Draft
Nor Afifah Yahaya: Supervision, Conceptualization, Methodology, Validation, Writing-Review & Editing, Resources
Hariz Saufi Mohd Sumari: Formal analysis, investigation, Methodology, Writing
Amalina Amir: Supervision, Conceptualization, Methodology, Validation, Writing-Review& Editing
Fauziah Jerai @ Junaidi: Supervision, Conceptualization, Methodology, Validation, Writing-Review& Editing
Amir Radzi Ab. Ghani: Supervision, Conceptualization, Methodology, Validation, Writing-Review & Editing

## DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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