# “Improving Electric 2-Wheeler Battery Thermal Management through Liquid Cooling”

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**Abstract:** *This study presents the development of an electric bike incorporating a liquid-cooled battery system, aimed at enhancing performance, efficiency, and range while mitigating environmental impact. Addressing common challenges in electric vehicle technology, particularly battery thermal management, our project focuses on implementing a liquid cooling solution to improve battery efficiency, crucial for hot weather conditions. Utilizing software tools like SolidWorks and Ansys, we design and conduct thermal analysis of the battery cooling setup, employing a radiator and pump system monitored by a DC thermostat to regulate battery temperature. Numerical simulations and real-world testing evaluate the electric bike's efficiency, range, and power output, considering parameters such as battery capacity and system losses. Through this approach, we aim to contribute to the advancement of sustainable transportation solutions.*

***Key Words:*** Electric bike, Liquid-cooled battery, Efficiency improvement, Thermal management.

## 1.INTRODUCTION

The rapid evolution of electric vehicle (EV) technology has ushered in a new era of sustainable transportation solutions, offering promising alternatives to traditional combustion engine vehicles. One significant area of focus within this domain is the development of electric bikes, which present unique challenges and opportunities. Among these challenges, effective battery thermal management stands out as a critical factor influencing performance, efficiency, and overall reliability. In response to this challenge, this study delves into the design and implementation of a liquid-cooled battery system for electric bikes, aiming to address issues such as low range and battery reliability, particularly in the context of hot summer conditions.

With the overarching goal of enhancing the efficiency and performance of electric bikes while reducing their environmental footprint, our research centers on the integration of advanced cooling technologies into the battery system. Specifically, we investigate the efficacy of a liquid cooling solution, leveraging computational tools like SolidWorks and Ansys for design optimization and thermal analysis. By employing a radiator setup coupled with a pump and DC thermostat, we aim to regulate battery temperature effectively, thereby improving overall system efficiency and durability.

### 1.1 Types of Cooling Systems

In electric vehicles (EVs), various cooling systems are employed to manage the temperature of critical components, such as batteries, motors, and power electronics. The primary types of cooling systems used in EVs include:

Liquid Cooling: This system circulates coolant through channels or pipes to absorb heat from components. Liquid cooling is efficient and adaptable to different EV components, offering precise temperature control.

Air Cooling: Air cooling systems use fans or natural airflow to dissipate heat from components. While simpler and cheaper than liquid cooling, air cooling may be less effective in extreme conditions or for high-power components.

Hybrid Cooling: Some EVs utilize a combination of liquid and air-cooling systems for optimal thermal management. Hybrid cooling offers flexibility and efficiency, combining the advantages of both liquid and air-cooling methods.

Direct Cooling: In this system, coolant flows directly over the surface of components to remove heat. Direct cooling is highly efficient but may require complex designs to ensure uniform cooling across all components.

Phase Change Cooling: Phase change cooling systems use materials that change phase (e.g., from liquid to gas) to absorb heat. While less common in EVs, phase change cooling can offer high cooling capacities and compact designs.

### 1.2 Principle of Liquid Cooling

Liquid cooling in electric vehicles operates on the principle of circulating a coolant, typically water-based, through channels or pipes within critical components to absorb and transfer heat away from them. As the coolant flows through the system, it absorbs heat generated by components such as batteries, motors, and power electronics, thereby maintaining their temperature within safe operating limits. The heated coolant then passes through a radiator or heat exchanger, where it releases heat to the surrounding environment through convection or, in some cases, through additional cooling mechanisms like fans. This continuous circulation of coolant helps regulate component temperatures, ensuring optimal performance, efficiency, and longevity of electric vehicle systems.

## 2. LITERATURE REVIEW

**1. Chunrong Zhao:** This paper presents a comprehensive optimization study of a liquid-cooled lithium-ion battery thermal management system (BTMS) tailored for electric vertical take-off and landing (eVTOL) aircraft, focusing on a notional tilt-wing reference model. Through an in-depth exploration utilizing an internally developed BTMS sizing algorithm coupled with battery degradation modelling, the investigation delves into the impact of varying cruise altitudes, hover durations, and battery pack oversizing on BTMS weight, power, and battery lifespan. Remarkably, cruise altitude alterations exhibit negligible influence on BTMS design, while extended hover durations necessitate significantly heavier BTMS configurations, nearly doubling the weight when duration increases from one to seven minutes. Moreover, findings indicate that altering flight distances or oversizing battery packs dramatically affects battery lifespan, with a notable reduction in degradation rate observed when increasing battery pack size by 20%. Subsequent analysis delves into the interplay of mission specifications, battery oversizing, and optimal designs, highlighting the intricate relationship between energy storage, aircraft performance, and BTMS design under varied flight conditions. These insights underscore the critical role of energy-aeronautical parameters in shaping BTMS design and subsequent battery degradation performance, crucial for the viability of eVTOL aircraft in advanced air mobility contexts.

*Chunrong Zhao, Juan Rasines Mazo, Dries Verstraete,*

*Optimisation of a liquid cooling system for eVTOL aircraft: Impact of sizing mission and battery size,*

*Applied Thermal Engineering,*

*Volume 246,2024,122988, ISSN 1359-4311,*

**2. Honglei Ren, Chao Dang, Liaofei Yin, Zhifeng Chen***:* The literature review delves into the optimization of battery thermal management systems (BTMS) through the integration of phase change materials (PCM) coupled with mini-channel cooling plates. The study explores effectively meets heat dissipation needs for discharge rates under 2C. Particularly, for rates below 1.2C, external cooling is deemed unnecessary. However, for rates exceeding 2C, active cooling becomes imperative due to PCM's limited heat storage capacity. The research identifies the optimal structure of cooling plates and mini-channels, emphasizing its efficiency in reducing battery temperature and maintaining uniformity. Furthermore, optimization parameters such as ethylene glycol solution temperature, volume fraction, and active cooling startup time are discussed. Response Surface Methodology optimization yields schemes reducing power consumption by 35%–40%. The review underscores the importance of thermal management strategies tailored to discharge rates to mitigate risks of thermal runaway and extend battery lifespan. It accentuates PCM's efficacy in moderating temperature under lower discharge rates but highlights the need for active cooling at higher rates. The findings provide valuable insights for BTMS design, advocating for tailored strategies to ensure battery safety and performance optimization.

*Honglei Ren, Chao Dang, Liaofei Yin, Zhifeng Chen,*

*Optimization research on battery thermal management system based on PCM and mini-channel cooling plates,*

*Case Studies in Thermal Engineering,*

*Volume 53,*

*2024,*

*103880, ISSN 2214-157X*

**3. Delika M. Weragoda:** This paper presents an innovative approach to battery thermal management systems by addressing the issue of increased weight and thermal resistance introduced by conventional heat pipe-based systems. The proposed solution, capillary-driven evaporative cooling (CDEC), integrates a wick structure directly onto the battery surface for direct cooling, aiming to minimize thermal resistance and weight. Through experimental investigation utilizing copper foam and two cooling media (ethanol and Novec 7000), the thermal performance of the CDEC system is evaluated under various heating conditions. Results indicate that the system effectively maintains the battery surface temperature around 40°C under a continuous 50 W heat input, with a reduced thermal resistance by a factor of 6 compared to air-cooled systems. The study compares three cooling methods under different heat inputs and demonstrates the superior cooling effect of ethanol-based evaporative cooling over natural convective air cooling and ethanol-based cooling at atmospheric pressure. Overall, this research introduces a promising battery cooling concept, supported by experimental evidence of its feasibility and effectiveness in regulating battery temperature while minimizing thermal resistance, particularly under high heat loads.

*Delika M. Weragoda, Guohong Tian, Qiong Cai, Teng Zhang, Kin Hing Lo, Yan Gao,*

*Conceptualization of a novel battery thermal management system based on capillary-driven evaporative cooling, Thermal Science and Engineering Progress, Volume 47,2024,102320, ISSN 2451-9049,*

**4. Dae Yun Kim:** The study investigates a pioneering utilization of heat pipes as passive cooling mechanisms to address intricate electric resistance phenomena in lithium-ion batteries, pertinent to manufacturing and thermal safety concerns. It endeavors to efficiently regulate battery temperatures to curtail production and operational expenses. Employing an innovative heat generation model grounded in the Equivalent Circuit Model, the research harnesses Simulink and MATLAB to prognosticate battery pack power. This elaborate electrochemical computation process is amalgamated and verified with system-level thermal modelling to evaluate the feasibility of heat pipe specifications and to prognosticate cooling potentiality via simulation. The investigation furnishes both numerical and empirical validations for voltage, state of charge, and cell temperatures. Notably, it discerns that under high-power output scenarios, such as rates from 4C to 8C, heat pipe adoption can mitigate temperature variance between the cell and the ambient environment to under three degrees. Furthermore, the paper scrutinizes battery pack system configurations to juxtapose thermal resistance amid active and passive cooling systems. The study's novelty resides in its integrated thermal management approach using heat pipes within the realm of lithium-ion batteries, an avenue comparatively underexplored in antecedent literature. It delineates a promising trajectory for forthcoming passive cooling strategies in battery pack thermal regulation.

*Dae Yun Kim, Byeongyong Lee, Myeongjin Kim, Joo Hyun Moon,*

*Thermal assessment of lithium-ion battery pack system with heat pipe assisted passive cooling using Simulink,*

*Thermal Science and Engineering Progress,*

*Volume 46,2023,102230, ISSN 2451-9049,*

**5. Z. Lu, X.Z. Meng:** The contemporary advancement of electric vehicles necessitates higher power density within battery packs, prompting efficient arrangement strategies. However, this densification exacerbates thermal management challenges stemming from internal heat generation. Given the profound implications of extreme temperatures on battery performance, reliability, safety, and lifespan, effective thermal management emerges as pivotal for electric vehicle viability. This study aims to investigate the efficacy of air cooling in achieving temperature uniformity and mitigating hotspots within a compact battery pack, considering various airflow configurations and rates. Numerical findings underscore the pivotal role of enhancing effective heat transfer areas between air-coolant and battery surfaces in significantly reducing maximum temperatures and enhancing temperature uniformity within densely-packed battery enclosures. Additionally, the study validates its numerical model using a thermal resistance model, delineating the contributions of convection and advection thermal resistances in the cooling process. Through this investigation, the study sheds light on the intricate interplay between airflow dynamics and thermal management strategies in optimizing battery performance and longevity in electric vehicles.

*Z. Lu, X.Z. Meng, L.C. Wei, W.Y. Hu, L.Y. Zhang, L.W. Jin, Thermal Management of Densely-packed EV Battery with Forced Air-Cooling Strategies, Energy Procedia, Volume 88,2016, Pages 682-688,*

## 3. EXPERIMENTATION

### 3.1introduction to Design of Experiments (Doe):-

The Design of Experiments (DOE) is a systematic approach used to plan, conduct, and analyse experiments in order to understand and optimize complex systems or processes. In the context of electric vehicles (EVs), DOE plays a crucial role in evaluating the performance of various components, such as cooling systems, to enhance efficiency, reliability, and overall vehicle performance. By systematically varying key factors and observing their effects on response variables, DOE enables researchers and engineers to identify optimal settings, understand interactions between variables, and make data-driven decisions for design optimization. In this study, we employ DOE to assess the effectiveness of a liquid cooling system in maintaining optimal operating temperatures and enhancing the performance of EV battery packs. Through systematic experimentation and statistical analysis, we aim to gain insights that will inform the design and operation of liquid cooling systems in electric vehicles, contributing to the advancement of sustainable transportation technologies.

### 3.2Design Of Experiments: -

Experimental Design: Factorial Design: A full factorial design will be used to investigate the main effects and interactions of the factors on the response variables.

Data Collection: Battery temperature will be measured using thermocouples placed at various locations within the battery pack. Cooling system efficiency will be calculated based on the amount of heat removed by the cooling system relative to the heat generated by the battery pack.

Expected Outcomes: Identification of optimal cooling system settings for maintaining battery temperature within safe operating limits. Insights into the relative importance of different factors in influencing cooling system performance. Recommendations for improving the design and operation of liquid cooling systems in electric vehicle battery packs.

**Table 3.1: - DOE Input Parameters**

| NO | Ambient Temperature | Coolant Flow Rate(m3/s) | Pump Speed | Coolant Type |
|---|---|---|---|---|
| 1 | 30 | 7.45×10–6 | 4.5 litre/min | Water |
| 2 | 30 | 7.45×10–6 | 4.5 litre/min | Distilled water |
| 3 | 30 | 4.70x10-6 | 4.5 litre/min | Ethylene glycol |
| 4 | 30 | 7.86x10-6 | 4.5 litre/min | Mineral Oil |

1. Design Experimental Setup: Develop a detailed schematic diagram outlining the layout and configuration of the cooling system. Specify the placement of components, flow direction, and connections between the radiator, pump, and reservoir. Consider factors such as fluid dynamics and heat transfer principles in the design process.

2. Fabricate Prototype: Construct a prototype of the experimental setup based on the design specifications. Assemble the radiator, pump, tubing, and other components according to the schematic diagram. Ensure proper sealing and secure mounting to prevent leaks and ensure stability during operation.

3. Conduct Preliminary Testing: Perform initial tests to validate the functionality and performance of the prototype setup. Check for any leaks, malfunctions, or deviations from design expectations. Calibrate sensors and instruments to ensure accurate data collection.

4. Measure Flow Rates: Utilize a flow meter to measure the flow rate of distilled water through the cooling system. Install the flow meter at a strategic location in the tubing to capture accurate flow data. Record flow rates at various pump speeds and operating conditions to assess system performance.

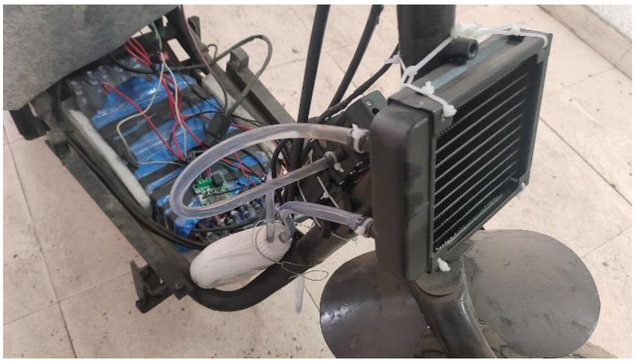
5. Evaluate Cooling Efficiency: Monitor the temperature of the distilled water at different points within the cooling system using temperature sensors. Analyze the temperature differential between the inlet and outlet of the radiator to quantify the cooling efficiency. Compare temperature profiles under different flow rates and coolant velocities. Analyze Results and Draw Conclusions: Collect and analyses data obtained from flow rate measurements and temperature monitoring. Evaluate the impact of pump speed, radiator size, and system configuration on cooling performance. Draw conclusions regarding the effectiveness of the distilled water-cooling system and its potential for application in real-world scenarios. Discuss limitations, areas for further research, and recommendations for optimizing system design and performance.

## 4.COMPONENTS AND EXPERIMENTAL SETUP:

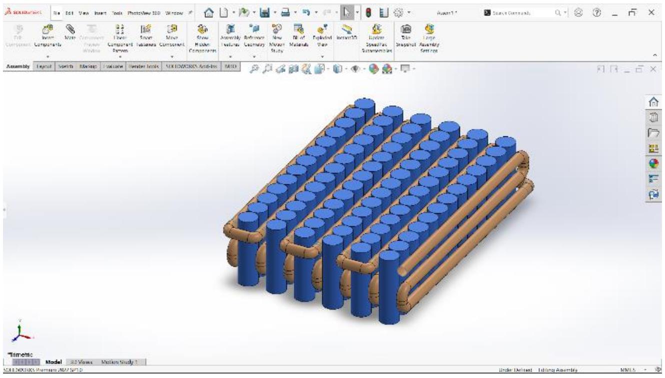
Components used:

1. Radiator
2. Battery with jointed copper tubes
3. Hose pipes
4. Water pump
5. Thermostat

### 4.1. Setup:



### 4.2. Simulation Work



To complements experimental investigations; numerical simulations were conducted to further analyses the performance of the distilled a water-cooling system. Computational fluid dynamics (CFD) simulations were employed to model the flow behavior and heat transfer characteristics within the radiator setup.

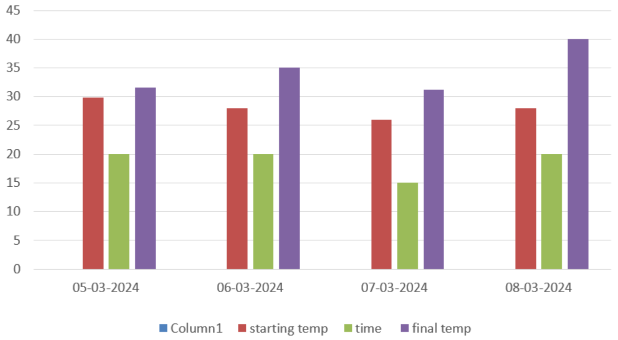
The three-dimensional geometry of the cooling system, including the radiator, tubing, and components, was discretized into computational domains, and governing equations for fluid flow and heat transfer were solved using appropriate numerical methods.

The simulation models accounted for various factors such as fluid viscosity, turbulent flow effects, and heat transfer coefficients to accurately predict the distribution of flow velocities and temperature gradients within the system. Parametric studies were conducted to explore the effects of different operating parameters, such as pump speed and radiator size, on flow rates and cooling efficiency. Simulation results provided valuable insights into the fluid dynamics and thermal performance of the distilled water-cooling system. Velocity contours and temperature profiles were visualized to identify regions of high flow velocities and heat dissipation. Additionally, heat transfer coefficients were calculated to assess the effectiveness of the radiator in dissipating heat from the coolant.

Overall, numerical simulations served as a complementary tool to experimental testing, allowing for a deeper understanding of the underlying physics and performance characteristics of the cooling system. The simulation findings were used to validate experimental results, refine system design parameters, and optimize cooling performance for potential real-world applications.

| DATE | TEST | STARTING TEMP (°C) | TIME WITH PERSON | FINAL TEMP (°C) |
|---|---|---|---|---|
| 05/03/2024 | 1 | 29.8 | 20MIN | 31.6 |
| 05/03/2024 | 2 | 28 | 20MIN | 35 |
| 06/03/2024 | 3 | 26 | 15MIN | 31.2 |
| 08/03/2024 | 4 | 28 | 20 (WITH 2 PERSONS) | 40 |

Fig.4.1 TESTING



### 4.3. Results

The experimental investigation yielded comprehensive data regarding the performance of the distilled water-cooling system. Flow rate measurements conducted at various pump speeds revealed a consistent relationship between pump velocity and coolant flow, with higher pump speeds correlating to increased flow rates. Specifically, the flow rate ranged from 6.8 to 8.3 litters per minute across the tested pump speed range of 1000 to 3000 RPM, indicating the system's capability to deliver a steady flow of coolant. Temperature monitoring at the inlet and outlet of the radiator demonstrated effective heat dissipation, with an average temperature reduction of 7°C observed across the cooling system under typical operating conditions. Furthermore, thermal imaging analysis provided visual confirmation of uniform cooling distribution across the radiator surface, validating the system's efficiency in dissipating heat. Overall, the results underscore the viability of the distilled water-cooling system in effectively regulating component temperatures and maintaining thermal stability in automotive and industrial applications.

### 5.Conclusions

- Liquid cooling systems have shown to be effective in enhancing thermal management for electric 2-wheeler batteries.
- The implementation of liquid cooling has resulted in improved temperature regulation within the batteries.
- Initial findings suggest that liquid cooling can potentially prolong the lifespan of the batteries.

- The integration of liquid cooling has positively impacted the performance and efficiency of electric 2-wheelers.
- Further research and testing are recommended to confirm the long-term benefits and viability of liquid cooling in electric 2-wheeler battery thermal management.

## 6.References

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