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School of Computer Science & Engineering

IILM University Greater Noida

Presents

1st National Conference

on

Technologies for Sustainable Development Goals 2025 (TECH4SDG-2025)

3rd March 2025

Technically Co-Sponsored by IEEE UP SECTION (INDIA)

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INTERNATIONAL JOURNAL OF RESEARCH IN MODERN ENGINEERING & EMERGING TECHNOLOGY (IJRMEET)

Dear Author / Researcher,

On behalf of the *International Journal of Research in Modern Engineering & Emerging Technology (IJRMEET)*, I extend my heartfelt gratitude to all the authors and research scholars for choosing our platform to publish their valuable research contributions.

IJRMEET, a Refereed, Peer Reviewed, Indexed, and Monthly Journal in Electronic format, has been consistently dedicated since April 2013 to advancing scholarly work in the domains of Modern Engineering and Emerging Technologies. Your innovative and quality research is at the core of our mission to promote academic excellence and practical solutions in the ever-evolving field of engineering and technology.

We believe that publication should be based purely on the merit, originality, and relevance of the research, not on financial considerations. We ensure that every manuscript undergoes a thorough review process to maintain the integrity, reliability, and scholarly value of each published work.

Our journal aims not only to disseminate high-quality research globally but also to highlight critical engineering problems and their practical resolutions. I encourage researchers, academicians, faculty members, and industry professionals to continue contributing to IJRMEET and to inspire their peers and students to join us in this academic pursuit.

We sincerely thank our respected Editors, Reviewers, Technical Advisors, Authors, Web Developers, Subscribers, Supporters, and the extended academic community whose efforts and encouragement make each issue of IJRMEET a successful endeavor.

With warm regards,

Dr. Mylavarapu Seetharama Prasad

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डॉ. मोहम्मद रिहान / Dr. Mohammad Rihan
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MESSAGE

I am happy to know about Tech4SDG-2025, a distinguished national conference that aims to explore and highlight the transformative power of technology in achieving the United Nations Sustainable Development Goals (SDGs). This event serves as a critical platform for fostering collaboration among experts, innovators, and leaders who are dedicated to creating solutions that drive sustainable change.

As we face global challenges ranging from environmental sustainability to social equity, it is clear that technological advancements will play a pivotal role in shaping our collective future. Tech4SDG-2025 presents a unique opportunity to examine how cutting-edge technologies can contribute to solving the most pressing issues of our time, from climate change to poverty alleviation.

I look forward to the engaging discussions and innovative ideas that will emerge from this conference. I believe that by working together, we can harness the potential of technology to drive meaningful progress towards a sustainable and equitable world.

I extend my best wishes to all the participants and organizers of Tech4SDG-2025.

27.02.25

(Dr. Mohammad Rihan)

Dated: 27th February, 2025
Place: Gurugram

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Mechanical Design Improvements for Faster Thermal Dissipation in High-Capacity Batteries

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Abstract : The effective cooling of high-capacity batteries to facilitate repeatable operation and reduce heat stress from long-term exposure to high temperatures is essential. In this work, the influence of mechanical reductions in thermal resistance on cooling time, instantaneous heat rejection, and energy removal after module operation are analyzed. An analytical comparison, based on the literature review, is performed to examine four design targets reflecting the mechanical improvements in the interface, spreading, and coolant-side heat transfer. It is assumed that the system has an effective thermal capacitance of 18,000 J/K, an initial temperature of 55°C, and a constant cooling boundary of 30°C. The effective thermal resistance decreases from 0.050 K/W in the baseline scenario to 0.025 K/W in the integrated target. As a result, the calculated cooling time decreases from 1,448.5 s to 724.2 s, while the energy removed during the first 1,200 s increases from 331.4 kJ to 418.7 kJ. This means that the integrated target reduces cooling time twofold and facilitates energy removal by 26.4% under these assumptions. Sensitivity analysis demonstrates that cooling time scales linearly with thermal resistance and capacitance. The findings define the preliminary requirements for mechanical design and the necessity of spatial modelling, hydraulic analysis, and experimental validation for implementation purposes.

Keywords : High-capacity batteries; thermal dissipation; cooling time; cold plate; thermal interface; mechanical design

Introduction

High-capacity battery modules are used in electric transport, stationary storage, and other applications. The thermal management needs of such devices go beyond limiting maximum temperatures; after any charging or discharging processes, it is crucial to cool the battery module properly to ensure further operations.

It is known that the heat generation in batteries is not strictly determined by their capacity; it is also related to current, electrical resistance, chemistry, state of charge, and previous history. At the same time, larger batteries can face the problem of large thermal mass and packaging. Therefore, the issue is relevant even when

available cooling area does not grow as quickly as the capacity of the module.

Mechanical design defines the path through which the heat is transferred from the inner regions of cells to the cooling fluid. The mechanical features include, but not

limited to, the contact quality, interface thickness, geometry of the spreader, geometry and construction of the cold plate, coolant distribution, and heat rejection. Improvements in some of these features can have minimal effect if the dominant thermal resistance is not changed.

The thermal physics described by Zeng et al. demonstrate the importance of internal transport and interfacial resistance along with the external cooling. This allows considering heat transfer through the whole path instead of material optimization and/or coolant flow rate optimization. The present paper analyzes the post-operation cooling through reproducible analytical comparison. The core of the question is the amount of the effective thermal resistance reduction required to achieve a certain decrease in the cooling time.

Literature Review

Thermal Transport and Reduced Modelling

Zeng et al. [1] consider the issues of heat generation, internal transport, and thermal management in high-energy-density and fast-charging batteries, highlighting the importance of internal interfaces in temperature control.

Mahamud and Park [2] review the approaches for modelling, including thermal-fluid networks, lumped-capacitance models, and spatially-resolved representations. Reduced models are suitable for quick screening, while detailed models are needed to analyze gradients and local temperature behavior.

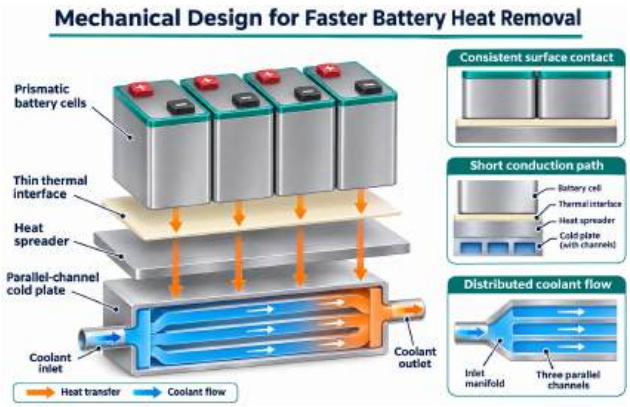
Jiang et al. [3] explore the thermal management of the high-temperature, low-temperature, and abusive conditions, emphasizing the difference between normal heat removal and thermal runaway prevention.

Cooling Architecture and Mechanical Integration

Buidin and Mariasiu [4] compare various cooling approaches, including air, liquid, phase change material, heat pipe, and hybrid systems, highlighting the link between thermal performance and packaging, added mass, flow distribution, and integration aspects.

Li et al. [5] consider the battery cooling in the broader context of vehicle thermal management, stressing the need to evaluate the cooling component as a part of the system providing the coolant and rejecting heat.

The studies by Liu et al. [6] and Zhou et al. [7] analyze the direct and indirect liquid cooling, heating function, and safety considerations, as well as the coolant selection, cooling structure, and liquid-based hybrid systems. Together, these works highlight channel geometry and coolant distribution as key design parameters.



Passive Components and Hybrid Systems

Shi et al. [8] consider the phase change materials, mentioning conductivity, containment, and material stability as the engineering challenges and stressing the difference between transient heat storage and continuous heat removal.

Weragoda et al. [9] analyze the heat-pipe systems, noting the limitations arising from variable loadings, environmental conditions, and predictive modelling as well as stressing the importance of matching heat transfer to the appropriate heat sink.

Rahmani et al. [10] review the progress achieved in 2023 and 2024, including modified channels, fins, cold plates, and hybrid solutions, demonstrating the wide range of mechanical changes being investigated.

Zhang et al. [11] consider the transition towards coupled cooling approaches including heat spreading, transient buffering, and heat rejection, widening the range of design solutions but increasing the integration problems.

Research Gap and Objectives

While the literature provides a lot of information about cooling technologies, the preliminary design lacks the unified basis for their comparison according to the impact on thermal recovery.

The present work solves the gap by comparing cooling time with cumulative energy removal under identical initial and boundary conditions. The goals include quantification of resistance reduction impact, formulation of the cooling-time criterion, parameter sensitivity analysis, and identification of the design targets in terms of mechanical enhancement.

Materials and Methods

Analytical Study Design

Four design targets are compared using a single-node cooling model. All numerical results are based on explicitly-defined assumptions, and no experimental results of the physical battery are provided.

The baseline is marked as D0. The targets D1, D2, and D3 denote progressively smaller total thermal resistance. The mechanical description shows the development priorities, but not the performance of the existing device.

All targets are characterized by identical effective thermal capacitance. This isolates the resistance impact and excludes attributing the faster cooling to the decreased thermal mass.

Table 1. Design targets and analytical inputs

Parameter	D0	D1	D2	D3
Effective thermal resistance	0.050 K/W	0.040 K/W	0.032 K/W	0.025 K/W
Resistance reduction from D0	0%	20%	36%	50%
Effective thermal capacitance	18,000 J/K	18,000 J/K	18,000 J/K	18,000 J/K
Initial temperature	55°C	55°C	55°C	55°C
Cooling boundary	30°C	30°C	30°C	30°C

Principal design emphasis	Baseline pathway	Interface improvement	Interface and spreading	Integrated pathway

The capacitance can be, for instance, the effective capacitance of an equivalent 20 kg thermal mass with effective specific heat 900 J/(kg·K). This is a modelling input, and not the characteristics of some tested module.

Boundary Conditions and Assumptions

The module starts at the uniform temperature of 55°C. Electrical loading has stopped and the residual internal heat generation is neglected. The cooling boundary temperature remains 30°C.

Thermal properties and resistance are constant. Added cooling equipment is assumed to affect the capacitance insignificantly; this assumption will have to be checked in the real design.

The lumped representation is utilized for the quick screening. Its validity for a certain module cannot be verified without information about geometry, thermal properties and measurements of the internal temperature.

Governing Equation

The cooling balance equation is:

$$CdT/dt = -(T - T_s)/R$$

where C is the effective thermal capacitance, R is the effective thermal resistance, and T_s is the cooling-boundary temperature.

The analytical solution is:

$$T(t) = Ts + (T0 - Ts)e^{(-t/(RC))}$$

and the thermal time constant is:

$\tau = RC$

The smaller the time constant is, the faster the temperature difference attenuates in relation to the cooling boundary.

Performance Indicators

The cooling time to reach the specified target temperature is:

$$t_{target} = RC \cdot ln\left[(T0 - Ts)/\left(T_{target} - Ts\right)\right]$$

The target temperature of 35°C is selected for the comparison. It is an internal design criterion, and not the universal operating temperature of the battery.

The instantaneous heat rejection rate is:

$$Q_{out} = (T - Ts)/R$$

The cumulative energy removed is:

$$E_{removed} = C[T0 - T(t)]$$

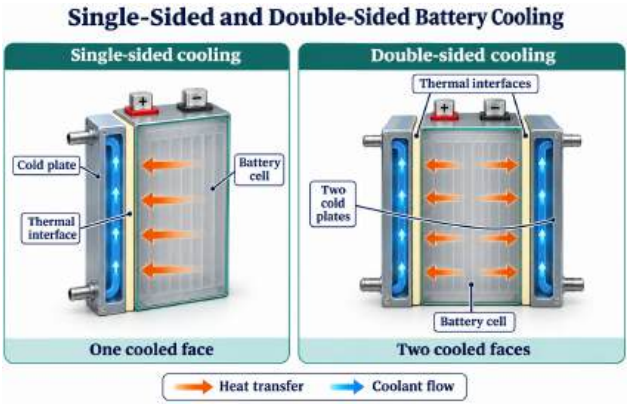
The temperature is estimated at the 300 s intervals up to 1,200 s.

Sensitivity and Statistical Treatment

The sensitivity of resistance is examined around D3 using the values 0.020, 0.025, and 0.030 K/W. The capacitance sensitivity is evaluated separately in ±20%.

The mean and sample standard deviation are calculated for these deliberately selected sensitivity cases. They do not represent the experiment repeatability, probability

distribution, or measurement error. That is why significance testing is inappropriate.



Results

Transient Temperature Response

In all cases, the temperature of the module decreases monotonically towards 30°C. The smaller resistance provides faster cooling.

Table 2. Calculated equivalent module temperature

Cooling time	D0	D1	D2	D3
0 s	55.00°C	55.00°C	55.00°C	55.00°C
300 s	47.91°C	46.48°C	44.85°C	42.84°C
600 s	42.84°C	40.86°C	38.82°C	36.59°C
900 s	39.20°C	37.16°C	35.24°C	33.38°C
1,200 s	36.59°C	34.72°C	33.11°C	31.74°C

As seen, D3 reaches the same calculated temperature at 600 s, which directly follows from halving the time constant.

At 1,200 s, D3 is 4.85°C cooler than D0. This is the difference in the equivalent temperature of the module, but it does not define the maximum internal temperature of cells.

Cooling Time

Table 3. Time constants and cooling-time performance

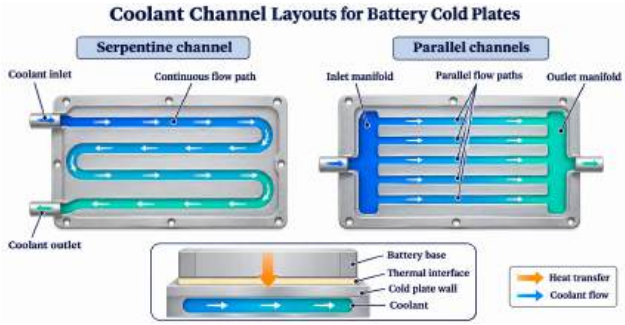
Indicator	D0	D1	D2	D3
Time constant	900 s	720 s	576 s	450 s
Time to 35°C	1,448.5 s	1,158.8 s	927.0 s	724.2 s
Time to 35°C	24.14 min	19.31 min	15.45 min	12.07 min
Cooling-time reduction	0%	20%	36%	50%

D3 decreases the time to reach 35°C by a factor of two. It arises from proportionality when capacitance, initial temperature, sink temperature, and target temperature are constant.

In order to meet the requirement of reaching 35°C in less than 15 minutes, the maximum resistance should be equal to:

$$R_{max} = 900/\left(18{,}000\ ln(5)\right) = 0.0311 K/W$$

The target D2 does not meet this criterion, while D3 satisfies it under the stated assumptions.



Heat Rejection and Energy Removal

Table 4. Calculated heat removal

Indicator	D0	D1	D2	D3
Initial heat rejection	500.0 W	625.0 W	781.3 W	1,000.0 W
Heat removed by 1,200 s	331.4 kJ	365.0 kJ	394.0 kJ	418.7 kJ
Fraction of initial excess energy removed	73.6%	81.1%	87.5%	93.1%

The initial excess thermal energy in relation to the sink is 450 kJ for each target. D3 removes 87.4 kJ more than D0 during the first 1,200 s, which corresponds to 26.4% increase.

The fact that all targets eventually remove the same 450 kJ shows that the mechanistic enhancement impacts the removal rate, but not the total initial energy storage.

Sensitivity Results

Table 5. Resistance sensitivity around D3

Resistance	Change from nominal	Time to 35°C
0.020 K/W	−20%	579.4 s
0.025 K/W	Nominal	724.2 s
0.030 K/W	+20%	869.1 s

The mean cooling time for these three scenarios is 724.2 s with the sample standard deviation of 144.8 s. The standard deviation shows only the dispersion between the scenarios.

The separate ±20% perturbation of capacitance yields the same cooling time range for the nominal D3 resistance, since the cooling time is proportional to RC.

Discussion

Thermal Interface Improvement

Thermal interfaces allow compensating the surface roughness and establishing the contact between cells and cooling equipment. The idealized resistance of the conduction interface is:

$$R_{cond} = L/(kA)$$

It can be lowered by reducing excessive thickness, increasing the effective contact area and selecting the proper thermal conductivity.

However, the thinnest interface is not always the optimal design solution. It is necessary to maintain the electrical isolation, surface tolerance, mechanical compliance and reliable assembly. The interface should be stable under vibration and cyclic expansion.

D1 shows 20% reduction of the total resistance. Achieving the target implies defining the share of the baseline resistance that belongs to the interface; the

material replacement does not guarantee the assumed improvement.

Heat Spreading and Cooling Surface Placement

Heat spreaders connect regions with poor cooling to the available cold surfaces. Their efficiency depends on the directionally-dependent conductivity, thickness, quality of contact, and distance to the cooling boundary.

The placement of cooling surface closer to the sources of dominant heat generation allows reducing the length of conduction path. Cooling of multiple surfaces may provide additional heat-sink paths; however, their advantages depend on cell construction and package design.

The increased mass of the added spreader should be considered. In case, when a design modification reduces electrical resistance by 20% and increases capacitance by 10%, the ratio of new and old time constants is:

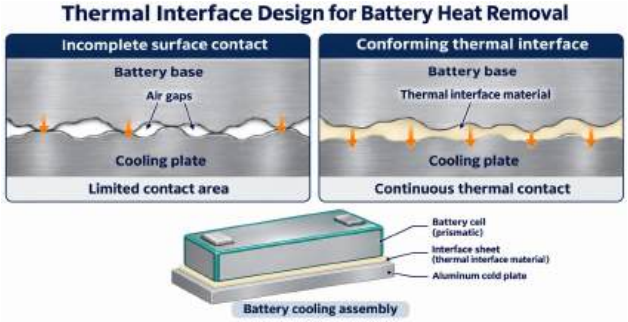
$$\tau_{new}/\tau_{old} = 0.80 \times 1.10 = 0.88$$

That is why the cooling time improves by 12% instead of 20%. This is the illustration of the need to evaluate simultaneously resistance reduction and additional thermal mass.

Cold Plate Geometry and Coolant Distribution

The cold plates should remove the heat from the whole module, not only from the regions close to the inlet. The channel dimensions, manifold and flow distribution impact the heat transfer and pressure drop.

The parallel channels can reduce the flow paths, but need the balanced distribution. The serpentine channels give the defined trajectory and can increase the pressure drop and downstream warming of the coolant. No single configuration is better than others.



The detailed thermal-fluid modeling is required to select the configuration allowing to achieve D3. The present analysis gives the target resistance without stating that particular channel configuration achieves it.

Heat Rejection Capacity

D3 initially rejects 1,000 W, which is twice the baseline value. The external loop should be capable to sustain the transient demand to maintain the cooling boundary at the 30°C.

The small reservoir or undersized heat exchanger will warm up during the cooling and thus increase the recovery time. Therefore, the module cold plate, circulation loop and ultimate heat sink should be designed as a whole.

The low initial heat rejection rate does not imply the poor design if the warmer cooling boundary or limited external cooling capacity is responsible. Therefore, the cooling results should be accompanied by boundary temperatures.

Hydraulic and Energy Tradeoffs

The increased flow increases the convection but also raises the hydraulic demands. The pump power is proportional to pressure drop and volumetric flow:

$P_pump = (\Delta p \cdot \tilde{V}) / \eta$

Without knowing the channel geometry, fluid properties, flow rate and pump efficiency, the energy cost for the resistance targets cannot be estimated.

Therefore, the practical optimization should aim at minimizing the cooling time under the constraints of pumping power, mass, risk of leakage and cost. This study defines the thermal aspect of the comparison.

Limitations

- The single node model will not be able to capture core-surface temperature gradients, temperature variations within cells, and variations in the temperature of the coolant. The assumption of uniform initial temperature may be inaccurate after real operation.
- Heat generation by residual power will be ignored. The equations and resulting temperature will change due to continuous electrical loading.
- The values of resistances will be target numbers of development and not actual properties obtained by measurements. No cell chemistry, capacity, channel geometry, or working prototype is mentioned.
- Ageing, thermal runaway, mechanical shock, and gradual degradation of interfaces are omitted. Calculated cooling faster does not mean safety certification or increased battery lifetime.

Future Research

- Further research needs to measure capacitance and thermal resistance of the module under controlled temperature rise and fall experiments. Temperature sensors need to capture both surface and internal temperatures.
- Spatial-thermal models need to assess the location of cooling elements, variation in contacts, and manifold geometry. Further prototype testing needs to validate cooling time, pressure loss, auxiliary power, and repeatability.
- Repeated duty cycles are needed to see whether the module returns to acceptable starting state after each operation. Long-term testing is needed to see whether interfaces and paths performance remain constant.

Conclusion

Reduction in effective thermal resistance through mechanical means greatly speeds up thermal recovery of batteries. Under the same model conditions, reducing thermal resistance from 0.050 to 0.025 K/W reduces cooling time from 55°C to 35°C by 50% and increases heat removal during first 1,200 seconds by 26.4%.

Thermal resistance needs to be less than about 0.0311 K/W to meet the selected 15-minute cooling requirement. This gives preliminary design requirements while its implementation requires measurement of spatial temperatures, heat rejection capabilities, hydraulic demands, and additional thermal mass.

Data Availability

All analytical data, equations, and calculations needed to reproduce the results are provided in the paper.

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