Improving 18650 Li-Ion Battery Cell Casing Design for Increasing Preconditioning Efficiency

Rajmond Jánó and Adelina-Ioana Ilieș

***Abstract*—The following paper aims to improve the casing of the standard 18650 Li-Ion battery cells in order to improve their preconditioning efficiency. The goal is to optimize the casing structure by adding additional surface area, with the aid of which these cells can reach their optimal charge/discharge temperature at a faster pace. This would result in less power consumed by the preconditioning (heating) circuit, which in turn would lead to better electric vehicle (EV) ranges and prolonged battery life. A series of different strategies are explored using FEM simulations and conclusions are drawn based on these, with the optimal casing configuration identified in the end. The research presented in this paper can help Li-Ion and EV manufacturers optimize their cells and setups for ideal battery preconditioning.**

***Keywords*—Li-Ion Battery, Preconditioning, Electric Vehicles.**

I. INTRODUCTION

For urban mobility vehicles, preconditioning Li-Ion batteries is essential to improving their overall efficiency, longevity, and performance. As the number of electric vehicles (EVs) in cities rises, it is more crucial than ever to guarantee the dependability and efficiency of their power sources. The process of carefully adjusting a battery's temperature prior to starting a driving cycle or a recharging event is known as "preconditioning". Because Li-Ion batteries are sensitive to temperature changes, this technique is especially important when it comes to EVs [1].

Because of their high energy density and capacity to provide the significant power output needed for urban mobility, Li-Ion batteries form the foundation of contemporary electric vehicles. But because of their intrinsic sensitivity to temperature changes, their longevity and performance may be greatly impacted. These batteries' electrochemical processes are optimized when operated within a specific temperature range, which maximizes energy efficiency and reduces degradation [2]. Preconditioning is an essential technique to guarantee that the batteries run within the optimal temperature range in urban transportation scenarios, where EVs frequently encounter a variety of harsh weather conditions.

A. The Effect of Temperature on Li-Ion Batteries

The impact of temperature on Li-Ion batteries' internal resistance is one of the main justifications for preconditioning. Internal resistance rises at low temperatures, resulting in poorer power output and slower charging rates [3]. This condition happens as a result of the electrolyte becoming more viscous and the chemical reactions inside the battery cells slowing down, which prevents ions from flowing freely between the electrodes. On the other hand, the risk of thermal runaway and rapid degradation rises at high temperatures despite the internal resistance falling. High temperatures can lead to capacity loss and possible safety risks by breaking down the electrolyte and decomposing the electrode materials. As a result, keeping the battery at the ideal temperature is crucial for both safe and effective functioning [4].

B. Cold Weather Performance Challenges

A key component in solving the problem of cold weather performance is preconditioning. Low temperatures cause Li-Ion batteries to lose capacity and efficiency, which reduces range and impairs overall EV performance [5]. The battery's electrolyte thickens in colder temperatures, which hinders ion flow. This leads to reduced power output and available capacity, which can be especially troublesome in metropolitan environments where stop-and-go traffic necessitates rapid acceleration [6][7].

Operators can lessen the effect of cold weather on battery performance by preheating the battery before usage, either by using the EV’s own thermal management system or by charging it via the grid. Preheating maintains the vehicle's anticipated range and performance levels by ensuring that the electrolyte achieves the ideal temperature for effective ion flow. In urban settings where unexpected battery performance might cause logistical problems and customer discontent, this procedure is essential for guaranteeing regular and dependable operation [8].

C. Improving Battery Durability

Preconditioning extends the battery's lifespan in addition to enhancing performance. Because materials expand and contract in response to temperature changes, battery cells may experience mechanical strains. These forces have the potential to shorten the battery's lifespan over time by causing microcracks to form and the electrode materials to deteriorate.

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These mechanical stresses are reduced via preconditioning, which keeps the temperature constant and increases the battery's usable life [9].

Degradation of batteries has an impact on performance as well as the bottom line. The cost of replacing a Li-Ion battery pack is high, but over the course of the vehicle's life, significant cost savings can be achieved by prolonging the battery's lifespan with the aid of efficient preconditioning.

D. Effect on Regenerative Braking Systems

Additionally, preconditioning improves the effectiveness of regenerative braking systems, which are frequently seen in EVs. When the car is slowing down, regenerative braking depends on the battery's capacity to absorb charge rapidly. Due to the increase of its internal resistance, the battery's capacity to absorb this regenerative energy is diminished at low temperatures, resulting in energy waste and a reduction in overall efficiency. Preconditioning increases the energy efficiency of the vehicle in stop-and-go urban traffic by ensuring that the battery is at the ideal temperature to collect regenerative braking energy [10].

E. Impact on Charging Times and Efficiency

The effect on charging times is another important consideration. One essential component of EVs' usefulness in urban environments is fast charging. However, because of the higher internal resistance, charging a cold battery may be slower and less effective. For consumers who depend on speedy turnaround times, EVs can be more convenient by preconditioning the battery to the ideal temperature prior to charging, which can shorten charging times and increase charging efficiency [11].

On the other hand, overheating a battery during charging can worsen deterioration and present safety hazards. Preconditioning protects the battery's performance and health by ensuring that the temperature is within an ideal range prior to charging.

F. Economic and Environmental Advantages

Effective battery operation lowers energy use and related emissions from power generation, which is good for the environment. Even though EVs have no emissions coming from their tailpipe, the electricity required to charge them might not be. The overall environmental impact of EVs can be decreased by increasing battery efficiency through preconditioning, particularly when taking the whole energy supply chain into account.

Preconditioning has the potential to save money for both users and operators. Over the course of the vehicle's life, improved battery longevity and performance translate into fewer replacements and cheaper maintenance expenses. These savings can be significant for fleet operators of urban mobility services like buses, taxis, and shared cars. Furthermore, because less energy is used, increased energy efficiency results in decreased operating expenses [12].

G. Employing Efficient Preconditioning Systems

The vehicle must have an efficient heat management system in order to implement preconditioning. The battery must be able to be heated and cooled by this system as needed. To accomplish exact temperature control, technologies including heat pumps, liquid cooling/heating systems, and sophisticated insulating materials are employed. Some of the advantages of preconditioning might be lost if these systems didn't integrate well enough to avoid using too much energy themselves.

Another important factor is the development of battery management systems (BMS). In order to maintain ideal conditions, a modern BMS can continuously monitor the battery's condition and modify the thermal management system as necessary. Proactive preconditioning is made possible by their ability to forecast temperature changes based on driving habits and ambient factors [13].

H. Owner Awareness and Behavior

Maximizing the advantages of preconditioning requires careful consideration of user behavior and awareness. The impact of preconditioning can be increased by teaching EV consumers about its benefits and proper usage. One way to guarantee that the battery is at the proper temperature prior to departure without consuming energy from the battery itself is to program the vehicle to precondition the battery while it is still connected to the grid. When planned during off-peak hours or when renewable energy sources are available, this technique makes use of grid energy, which is frequently more economical and sustainable [14].

I. Safety Considerations

Furthermore, preconditioning is important for safety reasons as well. Thermal runaway, a situation in which a Li-Ion battery overheats uncontrollably and may cause fires or explosions, can be increased by using the battery beyond its ideal temperature range. By guaranteeing that the battery temperature stays within safe bounds throughout operation and charging, preconditioning helps avoid such situations.

J. Innovations and Future Tendencies

The goal of research and development is to advance preconditioning technology. Battery preconditioning is becoming more effective and efficient thanks to innovations like phase change materials (PCMs) for thermal management, sophisticated predictive algorithms for temperature control, and interaction with smart grid systems [15].

Preconditioning procedures can be intelligently scheduled to benefit from off-peak electricity prices and renewable energy sources thanks to the connectivity with smart grids. By lowering dependency on fossil fuel-based energy generation, this not only lowers operating costs but also supports sustainability objectives [16].

Automated preconditioning can guarantee that vehicles are continually ready for use with the best possible battery performance in the context of shared mobility services and autonomous vehicles. Because the car performs consistently independent of the outside environment, this enhances the user experience.

In order to guarantee safety and performance across various manufacturers and models, regulatory agencies may also take into account standards and regulations for battery preconditioning as the market for electric vehicles expands. To create best practices and encourage broad adoption, industry stakeholders must work together.

K. Conclusion

To sum up, the preconditioning of Li-Ion batteries in EVs is a comprehensive strategy that improves longevity, performance, safety, and efficiency. It solves the problems caused by temperature changes, allowing EVs to function well in a variety of urban settings. EVs can function more dependably and efficiently, even in severe weather, by carefully controlling battery temperatures. Preconditioning will play a bigger part in guaranteeing the sustainability and viability of EVs as metropolitan areas continue to adopt electric mobility. Users, operators, and the environment will all gain from the wider shift to sustainable electric mobility, which will be facilitated by ongoing innovation and cooperation in this area.

II. PURPOSE OF THIS STUDY

The aim of this study is to improve the preconditioning characteristics of Li-Ion batteries, specifically 18650 Li-Ion cells. To achieve this, the initial preconditioning profile of a standard 18650 cell must be determined. After that, several strategies will be applied to increase the physical surface area of the cell in order to facilitate faster heat transfer between the preconditioning medium and the battery cell. The final goal is to provide Li-Ion cell manufacturers with a new design that would facilitate faster preconditioning times for 18650 cells and lead to more efficient charge/discharge cycles as well as prolonged battery life.

III. 18650 CELL MODELS USED

To evaluate the preconditioning time needed for different variations of the 18650 Li-Ion cell, thermal simulations were carried out using FEM simulations in a flow simulation software. The material characteristics of the cells were configured as presented in Table 1 and determined in earlier studies [17].

TABLE I: 18650 CELL MATERIAL CHARACTERISTICS

Property [Unit of Measurement]	Value
Thermal Conductivity [W/mK]	3.35
Density [kg/m3]	2725
Specific heat[J/kgK]	960

A. Standard (blank) model

The first model that was constructed is the model for an industry standard 18650 Li-Ion cell, as presented in Fig. 1. This model has a smooth surface and was used to evaluate the preconditioning time for 18650 Li-Ion cells currently available on the market.

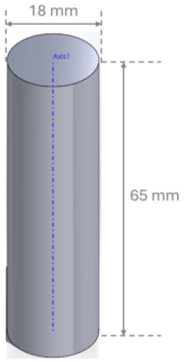

Fig. 1. Standard (blank) 18650 Li-Ion cell model.

B. Longitudinal grooves on casing

The first strategy to improve the overall surface area of the battery cell was to add grooves to its casing. The grooves were added to the whole length of the casing with a depth of 0.9 millimeters, and a width of 1 millimeter. Adding a total of 26 equally spaced grooves around the perimeter of the cell resulted in a spacing between the grooves of 1.15 millimeters. The design of the cell can be seen in Fig. 2.

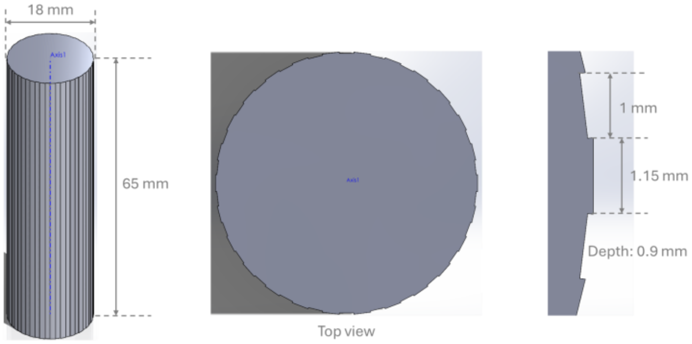

Fig. 2. 18650 Li-Ion cell model with longitudinal grooves on casing.

C. Round grooves on casing

The next strategy was to add round grooves around the casing of the cell. These were defined as having a depth of 0.5 millimeters around the body of the cell, a width of 1 millimeter and placed at 1-millimeter intervals. The design of the cell can be seen in Fig. 3.

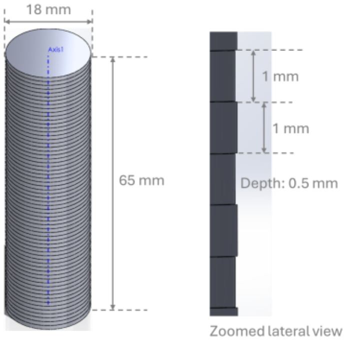

Fig. 3. 18650 Li-Ion cell model with lateral grooves on casing.

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D. Semicircle cutouts on casing

Another way of adding to the overall surface of the cell is to add rounded cutouts to the casing. These were defined to have a 0.5-millimeter depth and a diameter of 2.7 millimeters. A total of 22 cutouts were added vertically, while horizontally 13 were placed vertically, equally distributed on both axes. The design of the cell can be seen in Fig. 4.

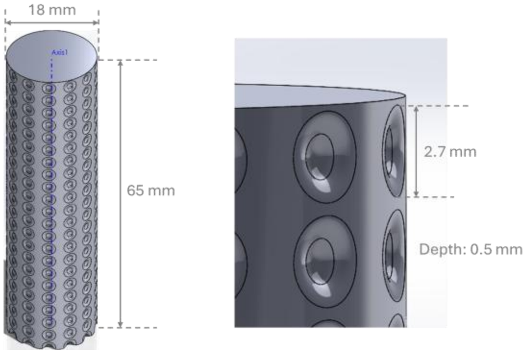

Fig. 4. 18650 Li-Ion cell model with semicircle cutouts on casing.

E. Dense semicircle cutouts on casing

The last pattern we designed to maximize the airflow and surface area of the cell was inspired by the efficient design used for golf balls. Since these are specifically designed to reduce drag and maximize travel distance, applying a similar pattern to the casing of an 18650 Li-Ion cell might also prove beneficial. Therefore, the semicircle cutout design from the previous point was adapted by multiplying the cutouts by increasing the number of cutouts vertically to 26 and horizontally to 20. This resulted in the design presented in Fig. 5.

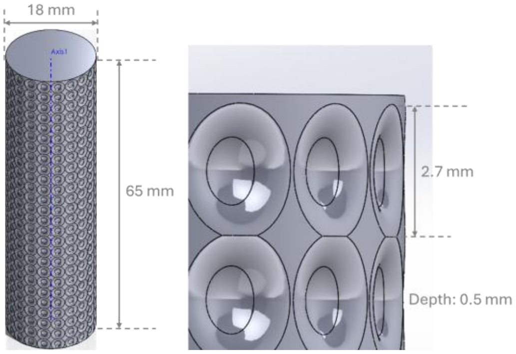

Fig. 5. 18650 Li-Ion cell model with dense semicircle cutouts on casing.

IV. SIMULATION SETUP

The goal of the simulations was to evaluate the preconditioning potential of the simulated cells. Therefore, a single cell was evaluated and the time it takes to reach 20°C from an initial temperature of 0°C was determined. For heating the cell, air at 25°C was used. This simulates the preconditioning of battery cells used in an EV.

Two scenarios were considered. In the first scenario natural convection was simulated. In this case, there was no forced airflow, the cell was placed at an initial temperature of 0°C in air at 25°C without any additional aid to move the air, besides gravity. However, since it is a significant factor when it comes to airflow during natural convention, the orientation of the cell was also considered in relation to gravity. The cells were evaluated in two cases, upright and in a horizontal position, as seen in Fig. 6.

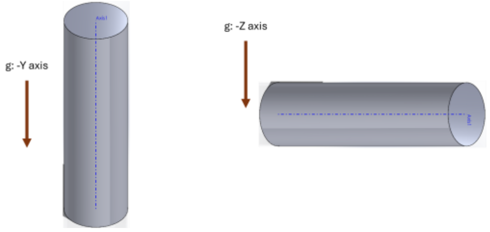

Fig. 6. Simulated cell positions.

In the second simulation scenario, forced convection was simulated. In this case, the air was blown at a speed of 5 m/s, again considering two scenarios: in parallel with the orientation of the cell and perpendicular to the body of the cell, as shown in Fig. 7.

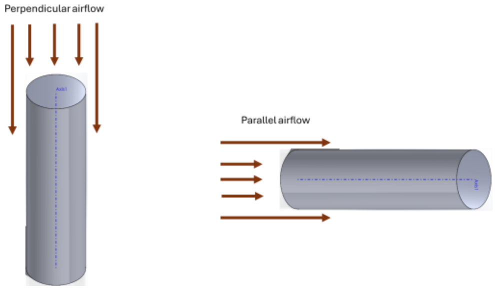

Fig. 7. Simulated airflow direction for forced convection.

V. RESULTS

A. Natural convection

The results for the simulations using natural air convection can be seen in Fig. 8. By analyzing these, we can draw two conclusions. Firstly, as expected, it can be seen that the position of the cell related to gravity has a significant impact on the preconditioning time for each cell type tested. Placing the cell horizontally (perpendicular to the gravity vector) will always yield a net advantage over placing the cell vertically (parallel to the gravity vector). The gains are presented in Table 2. As can be observed, gains between 16% and up to 20% can be obtained just by placing the cell perpendicular to gravity instead of parallel to it.

TABLE II: GRAVITY INFLUENCE ON PRECONDITIONING TIMES

	Placement		
Cell type	Parallel with gravity [s]	Perpendicular to gravity [s]	**Time Gain**
Blank	2784	2339	**16.0%**
Longitudinal_grooves	2723	2232	**18.0%**
Round_grooves	2726	2280	**16.4%**
Dimples	2658	2114	**20.5%**
Dimples_Dense	2699	2147	**20.5%**

On the other hand, when analyzing the influence of the strategies that were used to increase the surface area of the cell, we can conclude that the gains are marginal, at best. The best results are obtained by the model using the non-dense semicircle cutouts (labeled as “dimples” on the charts). However, even in this case we obtain a decrease of only 4.5% when the cell is placed upright and a decrease of 9.6% when the cell is placed perpendicular to gravity.

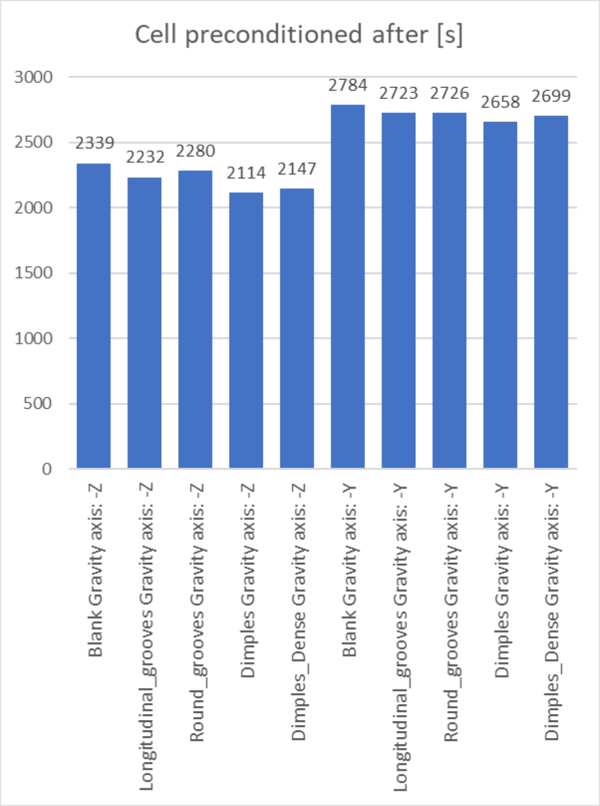

Fig. 7. Simulation results for natural air convection.

The very marginal gains can be explained by the following:

- Reduced Local Convection Efficiency:

The grooves can create “dead zones” or pockets of stagnant air where the convective motion is much weaker. Even though there’s more area, those parts may have a much lower effective heat transfer coefficient compared to a smooth surface that is uniformly exposed to the ambient air.

- Impeded Thermal Conduction

The metal in the grooved regions may not be as well thermally connected to the rest of the cylinder. This means the extra surface area doesn’t get “fed” with heat as efficiently from the interior of the cylinder, so the overall rate of heating can be slower.

- Altered Flow Patterns

In natural convention, the flow pattern around the object is critical. Grooves can disrupt the formation of an optimal boundary layer, potentially leading to less efficient heat transfer over parts of the surface.

B. *Forced convection*

When analyzing the results for forced air convention, presented in Fig. 8, however, the results are much better. The gains are presented in Table 3.

In this case, there is a clear improvement in many scenarios, however by far the most favorable being the addition of round grooves to the casing of the battery. For this setup we see a halving of the time needed for preconditioning in case the cell is perpendicular to airflow and a 60% gain when the cell is placed parallel to airflow.

TABLE III: FORCED CONVECTION RESULTS

Model	Gravity	Preconditioning time [s]	Gain
Standard	Perpendicular	325.0	Baseline
Longitudinal_grooves	Perpendicular	317.0	2.5%
Round_grooves	Perpendicular	161.0	50.5%
Dimples	Perpendicular	232.0	28.6%
Dimples_Dense	Perpendicular	174.5	46.3%
Standard	Parallel	466.0	Baseline
Longitudinal_grooves	Parallel	638.5	-37.0%
Round_grooves	Parallel	176.5	62.1%
Dimples	Parallel	444.5	4.6%
Dimples_Dense	Parallel	383.0	17.8%

Some scenarios, on the other hand, do not offer positive outcomes, such as when adding longitudinal grooves and placing the cell in parallel to the airflow. In this aforementioned case the preconditioning time is increased by 37%.

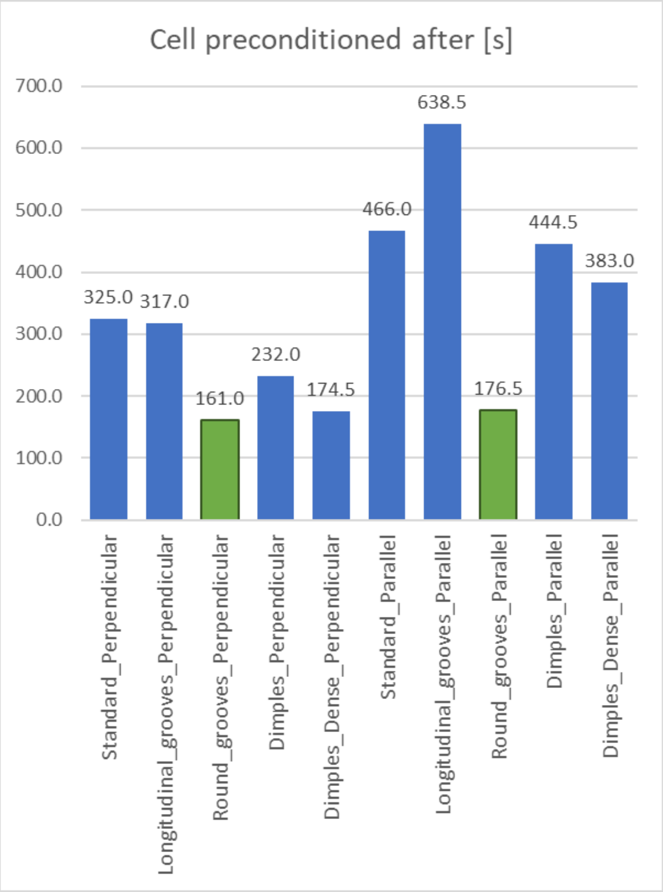

Fig. 8. Simulation results for forced air convection.

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VI. CONCLUSIONS

The aim of this paper was to find ways of improving the preconditioning efficiency of a standard 18650 Li-Ion cell. In order to achieve this, different configurations were designed to increase the surface area of the battery cell to facilitate heat transfer. The proposed configurations were then analyzed using FEM simulations both in static conditions using natural convection as well as using forced airflow.

For natural convection the conclusions we can draw are twofold: on one hand, the results show that adding additional patterns to the battery casing does not significantly improve the preconditioning time. The improvements are so marginal that in this case, the additional costs generated by the proposed strategies would not be justifiable. On the other hand, however, these simulations have shown that the placement of the cell in relation to gravity has a significant impact. Therefore, we can recommend to EV manufacturers that cells should always be placed perpendicular to the gravity vector, where possible, since this will increase the efficiency of natural convection preconditioning.

In the case of forced air convection, a very significant gain was achieved regarding preconditioning times when adding shallow round grooved to the casing of the battery. With more than halving the time needed for preconditioning, in both vertical and horizontal placement, this strategy can be clearly recommended to be used in electric vehicles with these types of cells. Additionally, decreasing preconditioning times would also result in less power usage for battery preconditioning, which in turn increases the range of the EV, all the while ensuring the health and longevity of the batteries.

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REFERENCES

[1] Y. Wang, X. Zhang, Z. Chen, “Low temperature preheating techniques for Lithium-ion batteries: Recent advances and future challenges” Applied Energy, vol. 313, 2022. https://doi.org/10.1016/j.apenergy.2022.118832

[2] M. A. Rosen, A. Farsi, “Battery Technology. From Fundamentals to Thermal Behavior and Management”, Elsevier, 2023. https://doi.org/10.1016/B978-0-443-18862-6.00005-7

[3] S. Wu, R. Xiong, H. Li, V. Nian, S. Ma “The state of the art on preheating lithium-ion batteries in cold weather” Journal of Energy Storage, vol. 27, 2020. https://doi.org/10.1016/j.est.2019.101059

[4] H. Liu, Z. Wei, W. He, J. Zhao, “Thermal issues about Li-ion batteries and recent progress in battery thermal management systems: A review,” Energy Conversion and Management, vol. 150, pp. 304-330, 2017. https://doi.org/10.1016/j.enconman.2017.08.016

[5] Y. Wang, X. Zhang, Z. Chen, “Low temperature preheating techniques for Lithium-ion batteries: Recent advances and future challenges”, Applied Energy, vol. 313, 2022. https://doi.org/10.1016/j.apenergy.2022.118832

[6] M. Petzl, M. Kasper, M.A. Danzer, “Lithium plating in a commercial lithium-ion battery – A low-temperature aging study,” Journal of Power Sources, vol. 275, 2015. https://doi.org/10.1016/j.jpowsour.2014.11.065

[7] J. Jaguemont, L. Boulo, et. al., „Lithium-Ion Battery Aging Experiments at Subzero Temperatures and Model Development for Capacity Fade Estimation,” IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, vol. 65, 2016. https://doi.org/10.1109/TVT.2015.2473841

[8] X. Wu, Z. Cui, E. Chen, J. Du, “Capacity degradation minimization oriented optimization for the pulse preheating of lithium-ion batteries under low temperature,” Journal of Energy Storage, vol. 31, 2020. https://doi.org/10.1016/j.est.2020.101746

[9] J. Jaguemont, L. Boulon, Y. Dubé, “A comprehensive review of lithium-ion batteries used in hybrid and electric vehicles at cold temperatures” Applied Energy, vol. 164, 2016. https://doi.org/10.1016/j.apenergy.2015.11.034

[10] D. Ramsey, A. Bouscayrol, L. Boulon, “Energy Consumption of a Battery Electric Vehicle in Winter Considering Preheating: Tradeoff Between Improved Performance and Total Energy Consumption”, IEEE Vehicular Technology Magazine, vol. 17, no. 3, pp. 104-112, 2022. https://doi.org/10.1109/MVT.2022.3158043

[11] J.G. Qu, Z.Y. Jiang, J.F. Zhang, “Investigation on lithium-ion battery degradating induced by combined effect of current rate and operating temperature during fast charging”, Journal of Energy Storage, 52, 2022. https://doi.org/10.1016/j.est.2022.104811

[12] Q. Zhang, B. C. Mclellan, T. Tezuka, K. N. Ishihara, “A methodology for economic and environmental analysis of electric vehicles with different operational conditions” Energy, 61, 118-127, 2013. https://doi.org/10.1016/j.energy.2013.01.025

[13] R. Q. K. Frank, “Thermal Management of Lithium-Ion Battery Pack” Product Development and Materials Engineering, 2020.

[14] T. Zhu, H. Min, Y. Yu, Z. Zhao, T. Xu, Y. Chen, et. al., “An Optimized Energy Management Strategy for Preheating Vehicle-Mounted Li-ion Batteries at Subzero Temperatures”, Energies. 2017. https://doi.org/10.20944/preprints201612.0029.v1

[15] M. Steinstraeter, J. Buberger, K. Minnerup, et. al., “Controlling cabin heating to improve range and battery lifetime of electric vehicles”, eTransportation, vol. 13, 2022. https://doi.org/10.1016/j.etran.2022.100181

[16] Å. L. Sørensen, B. Ludvigsen, I. Andresen., “Grid-connected cabin preheating of Electric Vehicles in cold climates – A non-flexible share of the EV energy use”, Applied Energy, 341, 2023. https://doi.org/10.1016/j.apenergy.2023.121054

[17] R. Jano, A. I. Ilies, A. Fodor, “Thermal Simulations for 18650 Li-Ion Batteries”, 2022 IEEE 28th International Symposium for Design and Technology in Electronic Packaging (SIITME), 2022. https://doi.org/10.1109/SIITME56728.2022.9987899

[18] D. Oehler, J. Bender, P. Seegert, T. Wetzel, “Investigation of the Effective Thermal Conductivity of Cell Stacks of Li-Ion Batteries”, Energy Technol., 9, 2021. https://doi.org/10.1002/ente.202000722