Celal Bayar University Journal of Science
Volume 19, Issue 3, 2023, p 205-210
Doi: 10.18466/cbayarfbe1247445

Celal Bayar University Journal of Science

Modeling of the Cooling of the Batteries of Electric Vehicles Using the Cabin Air Conditioning System

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Received: 03 February 2023
Accepted: 19 September 2023
DOI: 10.18466/cbayarfbe1247445

Abstract

In this study, a simulation on management of battery temperature, which is a significant problem for electric vehicles, has been made. Battery temperatures can reach up to 50 °C if not checked during quick charging and discharging processes. Such situation shortens the lifetime of battery and also increases the temperature inside the cabin. More importantly, they can be dangerous. LMS Amesim software and WLTC driving cycle have been used for the simulation. Three battery packages have been used in simulations. Temperature of the battery have been checked at three different ambient temperatures (25 °C, 30 °C, 35 °C). During the test, it has been enhanced to keep the battery temperature below 35 °C under all conditions. Air-conditioner of the vehicle has been used to cool the batteries. When the temperature increased, the air-conditioner automatically checked the operating cycle of the compressor and cooled the batteries by means of constant air flow. In conclusion, the simulation has kept the battery temperature at desired level at ambient temperatures of 25 °C and 30 °C. At ambient temperature of 35°C, battery temperature increased up to 35.2°C.

Keywords: Battery temperature management, Electric vehicle, Hybrid electric vehicle, WLTC driving cycle.

1. Introduction

Global warming and environment pollution have increased rapidly due to recent development of industry. Especially carbon emission during generation and use of technology and mixing of pollutants into nature have become a major problem of the world. Internal combustion engines used nowadays in vehicles are the most important elements causing environment pollution and global warming [1]. Therefore, their production has started to be restricted throughout the world. Especially, all internal combustion engines, primarily diesel engines, are subjected to heavier driving cycles when compared to past and are forced to be less pollutant [2, 3]. However, it becomes impossible day by day to keep up with such cycles due to physical effects. Manufacturers have intensified their works on hybrid or electric vehicles, which sense such hard conditions less, in order to meet the vehicle requirements of the society [4]. In general terms, hybrid engines include a gasoline internal combustion engine and a small electric motor supporting the former one in certain circumstances [5]. In fact, hybrid engine makes the traditional vehicle with internal combustion engine much more complicated. Systems, requiring more parts and maintenance, are altogether [6]. The electric motor operates less quietly and more environment-friendly during urban and easy driving, and complies with driving cycles. Here, there is a small lithium battery providing energy to the electric motor. [7]. In the beginning, hybrid vehicles used to be charged only during the driving process while new hybrid vehicles can be charged by charger. Hybrid vehicles are actually a start directing the society to full transition to electric automobiles. In the following years, the roads will be occupied completely by electric vehicles. Electric vehicles have a plainer structure when compared to the hybrid ones. Electric motors included in their structure are the only elements providing power and making the driving wheel. Therefore, they can operate completely environment-friendly and quietly during their use [8]. Moreover, they can easily adapt themselves to driving cycles under the harshest conditions. The electric motor can be on both front wheels or on four wheels in certain brands. In such engines, the power is generally provided

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by means of lithium-ion batteries/accumulator placed on the basement of the vehicle. Compared to the batteries found in hybrid vehicles, these batteries in electric vehicles are larger in terms of weight and size and contain more power. [9]. Depending on the size and using purpose of the vehicles, electric engines at various powers and batteries at supportive power are selected [10]. As during the driving process, whole energy is provided by such batteries, their volume and weight are great. This situation increases the weight of the vehicle and shortens the distance to be covered and increases the re-charging duration. Electric vehicles are also subjected to driving cycle just like vehicles with internal combustion engine and hybrid engines [11-12]. This is a driving cycle operating according to theoretical test procedures of New European Driving Cycles (NEDC), which entered into force in 1980 and have become outdated [13]. As theoretical data are used, changes and emission values occurring in real driving cannot be put forward. Today, Worldwide Harmonised Light Vehicles Test Procedure (WLTC), accepted in 2017, is used [14]. In this cycle, real driving conditions are used for vehicles and a more realistic emission and speed/fuel consumption values occur. There are many theoretical and experimental researches in which driving cycles are applied on hybrid and electric vehicles. Some of them have intensified in energy consumption [15]. In such studies, battery consumptions in different driving cycles have been examined. In some of them, battery charging amount of regenerative gains have been put forward [16].

Effects of the heat emerging in battery during use can be considered as a significant research subject. The researches have focused on methods for protection against negative effects of such heat or prevention of increasing the temperature of battery above critical level. [17-19]. The batteries start to get dicharged quickly in power-requiring regions and accordingly their temperature increases. The increase in temperature is an important element shortening the lifetime of battery [20-21]. In a study, ammonium was used to cool lithium-ion batteries [22]. In another study, LiFePO4 batteries used in electric vehicles were cooled with water-passing plates [23]. In previous studies, comparisons of liquid-cooled, air-cooled conventional battery cooling systems with thermoelectric element-based, phase-change material-based, heat pipe-based battery thermal management systems were made [24]. This study is on modelling of an electric vehicle by means of LMS Amesim simulation programme produced by Siemens Industry Software company. The vehicle used in such model is tested by WLTC cycle. The battery temperature occurring during related time has been cooled by the air-conditioning system of the vehicle.

2. Modelling and Simulation conditions

LMS Amesim simulation programme can achieve design and simulation in various parts of heavy-duty type vehicles, automotive, aircraft industry, defence industry, mechanical and production stages. In such kind of programmes, the parts and sections composing the system are selected and a work which is closer to real test procedures can be achieved. In the model, which is subject of this study, it has been tried to prevent temperature increase in the battery and to provide cabin comfort for the passengers during the driving by means of air-conditioning system.

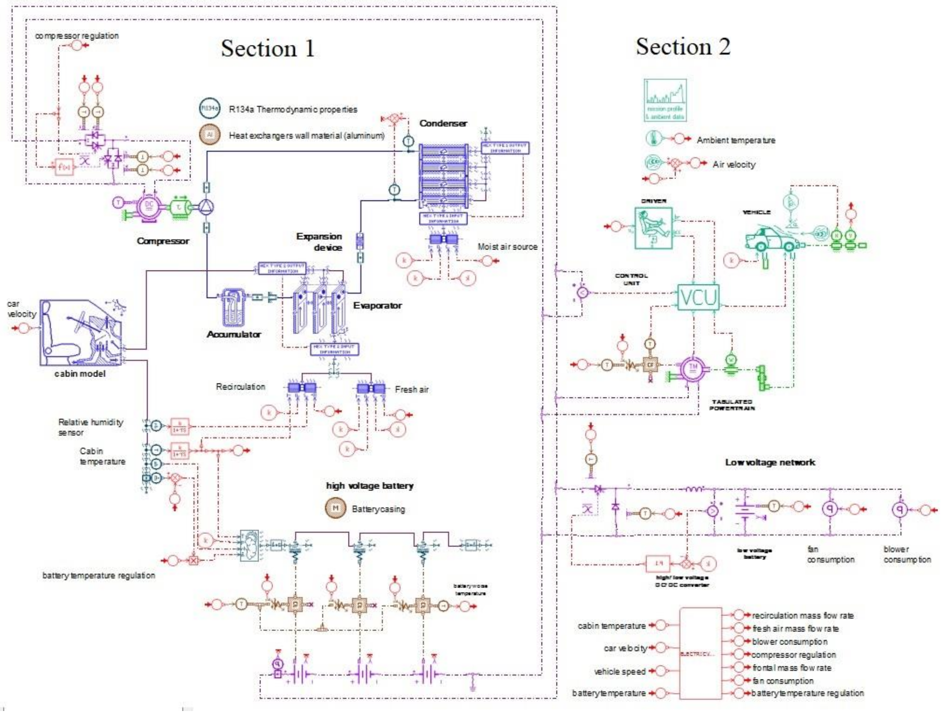

Figure 1. Design screen of the programme.

The system is composed of two parts. In the first part, a scheme required for operation of the air-conditioner is included, and in the second part, the scheme showing the driving cycle of the electric vehicle is included. The battery temperature has been tried to keep under 35ºC by a part of the air of the air-conditioner. At the same time, the air-conditioner has been programmed in a manner not disturbing basic comfort of the passengers.

The programme scheme is shown is Figure 1. In the air-conditioning system, R134 coolant gas and a direct current compressor with constant magnet have been used. Air properties inside and outside the vehicle cabin have been given in Table 1. Here, cabin volume has been designed as 3.5 m^3.

Table 1. Properties of the air inside and outside the cabin.

Cabin volume	3.5 m^3
Wall thermal capacity	15000 J/ºC
Internal exchange surface	15 m^2
Cabin initial relative humidity	% 40
External pressure	1.013 bar
Solar flux	1000 W/m^2

Vehicle battery is composed of 3 cells, each of which is 160 Volt, connected serially to each other and having a total capacity of 40 KWh. At the beginning of the test, the battery is charged by 80%. Features of the test vehicle have been given in Table 2.

Table 2. Features of the Test Vehicle.

Total vehicle mass	1400 kg
Mass distribution	50 %
Wheel inertia	0.75 kgm^2
Tire width	165 mm
Tire height	65 %
Wheel rim diameter	15 in
rolling resistance coefficient	0.01
Air penetration coefficient (Cx)	0.3
Vehicle active area for aerodynamic drag	2 m^2
Friction coefficient	1.2

During simulation, desired driving cycle can be selected. In this study, WLTC driving cycle has been used. Features of such driving cycle have been given in Table 3. In this cycle, maximum speed is 131 km/h; average speed is 46.5 km/h; total driving cycle is 1800 s and cycle lenght is 23.25 km.

Table 3. Features of WLTC driving cycle.

Cycle Time	30 min.
Cycle Distance	23.25 km
Driving Phases	52% urban, 48% extra-urban
Average Speed	46.5 km / h
Max Speed	131 km / h
Test Temperatures	23 °C
Total Time (s)	1800
Max. Acceleration (m/s²)	1.7
Max. Deceleration (m/s²)	-1.5
Fixed Driving Time (s)	66 (3.5%)
Acceleration Time (s)	789 (44%)
Deceleration Time (s)	719 (40%)
Stop Time (s)	226 (12.5%)

The simulation carries out WLTC cycle respectively at ambient temperatures of 25ºC, 30 ºC and 35 ºC. At that moment, while the battery temperature is prevented to exceed 35ºC, temperature comfort inside the cabin has been tried to be met. The air-conditioning system has programmed air-conditioner compressor to turn at appropriate cycles in order to fulfil such conditions. The air is let at a constant flow in order to cool the battery when required. The main reason of this is to make the temperature comfort inside the cabin more efficient in all conditions.

2. Results and Discussion

In Figure 2, there is a graphic showing the WLTC driving cycle and the compliance of the test vehicle with such cycle. The cycle also includes the speed area. The change in battery temperature at the end of the simulation has been obtained depending on the time. Especially in regions requiring high power, increase in battery temperature is an expected result. At that moment, cycle of air-conditioner compressor is increased and the battery is cooled by producing more coolant.

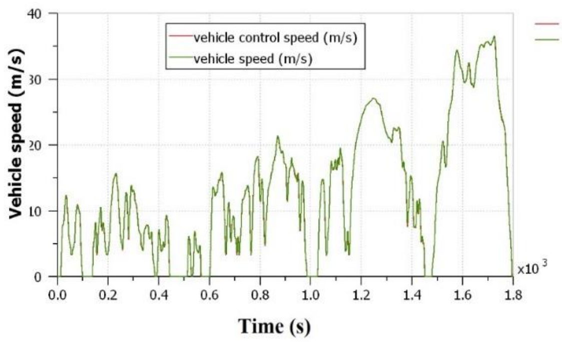

Figure 2. Speed-time graphics of test vehicle and WLTC driving cycle.

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In Figure 3, the graphic including time-dependent battery temperature while the ambient temperature is 35ºC, and mass flow of the air coming from the air-conditioning system. The battery temperature has started the cycle with a temperature of 35 ºC which is equal to the ambient temperature. The system sends the coolant air into the battery according to the temperature of the hottest battery package.

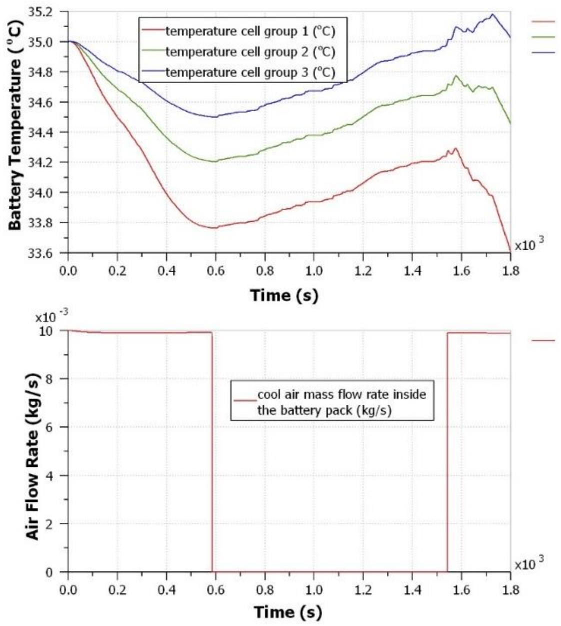

Figure 3. Temperature changes and air flow rate in battery packages while the ambient temperature is 35 ºC.

At that moment, the air conditioner compressor is active. Hence, the air is sent to 3 battery packages by a flow rate of 0,01 kg/s. It is understood from the graphics that the battery temperatures drop quickly when it is started to send air to the battery packages. The first battery package located in front of the air inlet cools firstly; the other packages located at the back remain warmer. At the last part of the cycle requiring high power, there is an excessive energy consumption, and the battery package located backmost is a bit above 35ºC. When whole cycle is examined, all battery packages have remained under 35.2ºC.

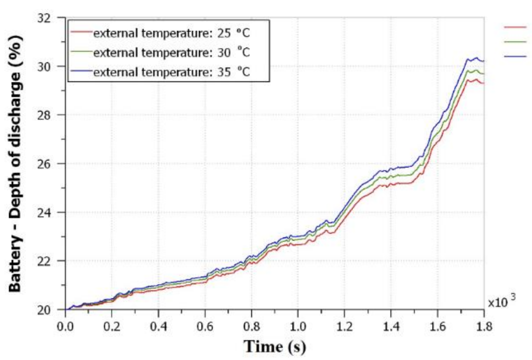

Figure 4. Time-dependent change of battery's deep cycle percentage.

In Figure 4, change of battery discharge during the whole cycle is shown. At the beginning of the cycle, the battery is 20% empty. Here, results of driving tests at 3 different ambient temperatures are included. At ambient temperature of 35 ºC, deep cycle of the battery has increased above 30%. Ambient temperature of 30 ºC has caused less battery consumption. The lowest consumption is observed at 25 ºC. As it can be understood that as the ambient temperature decreases, battery consumption decreases too.

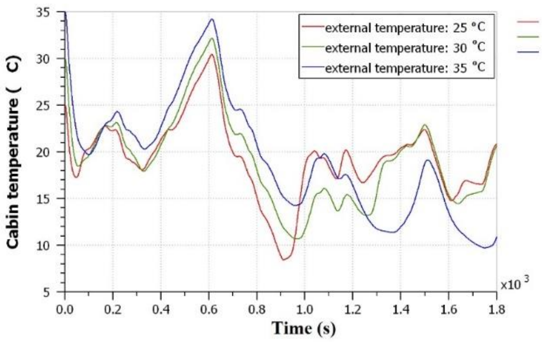

Figure 5. Time-dependent change of cabin temperature.

In Figure 5, change of cabin temperature during the cycle is shown. The tests have been made in three different ambient temperatures again. At the beginning of driving, cabin temperature is equal to the ambient temperature. As soon as the driving begins, the air-conditioner compressor starts to operate and cools both the battery and the cabin. In order to make cabin temperature below 25 ºC, the coolant air is continued to be sent inside the cabin. At the 600th second of the cycle, the battery temperature drops below the targeted value. The air-conditioning air given to the battery is cut off at that moment and therefore battery temperature increases immediately. Such situation increases the cabin temperature quickly too.

As soon as the battery temperature reaches up to 35 ºC, the coolant air is directed again to the battery and accordingly temperatures of both cabin and the battery decrease.

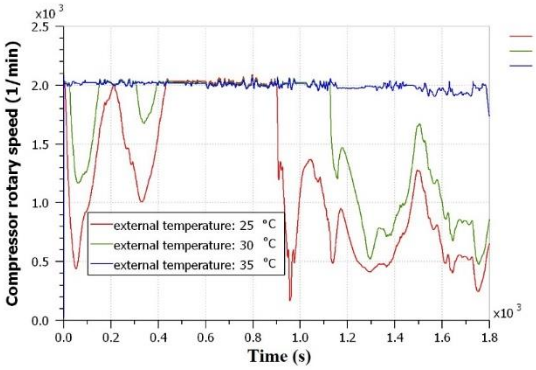

Figure 6. Time-dependent change of rotary speed of air-conditioner compressor.

In Figure 6, time-dependent change of rotary speed of air-conditioner compressor has been given. The compressor rotates at a maximum speed of 2100 1/min. When the graphic is examined, it is observed that the compressor rotates at a value close to the highest speed at 35 ºC. The main reason of this is the fact that ambient temperature is high and accordingly battery temperature increases constantly. Such two increases result in significant increase in cabin temperature. The speed of the compressor is less at ambient temperature of 30 ºC and 25 ºC respectively. At those temperatures, the cabin temperature increases especially at the 400th second. The system increases the compressor cycle at the highest level as a reaction to this.

3. Conclusion

When simulation findings are examined, it is observed that battery temperature increases depending on the ambient temperature. At the same time, the quick increase in battery consumption in regions requiring high power according to WLTC cycle increases the battery temperature as well. Placement of battery packages at the basement of the vehicle increases the cabin temperature and affects the comfort of the passengers. As both battery temperature and cabin temperature are tried to be decreased by means of air-conditioner, the air-conditioner compressor cuts in more in hot weather and rotates at higher speed. Another conclusion derived from the tests is the higher level of battery's deep cycle in hot weather conditions. It has been observed that as the temperature increases, battery consumption increases too. In electric vehicles, batteries must be cooled. To this end, liquid cooling can be an effective method apart from the one studied here in.

Author's Contributions

Haluk Güneş: Drafted and wrote the manuscript, performed the experiment and result analysis.

Ethics

There are no ethical issues after the publication of this manuscript.

References

[1]. Behi, H., Karimi, D., Jaguemont, J., Gandoman, F.H., Kalogiannis, T., Berecibar, M., Mierlo, J.V. (2021). Novel thermal management methods to improve the performance of the Li-ion batteries in high discharge current applications. Energy, 224: 1-17. https://doi.org/10.1016/j.energy.2021.120165.

[2] Kunt, M.A. (2022). Analysis of engine and powertrain losses of a passenger type 4-stroke gasoline vehicle in 4 different driving cycles with gt-suıte vehicle simulation program. International Journal of Automotive Science and Technology, 6(4): 340-346. https://doi.org/10.30939/ijastech.1152980.

[3] Kunt, M.A. (2021). Analysis of The Effect of Different Gearbox/Transmission Types on Driveline Friction Losses by Means of Gt Suite Simulation Programme. International Journal of Automotive Science and Technology, 5(3): 271-280.

[4] Sevim, E., Çetin, E. (2022). The performance comparison of the sic and si mosfets used in the 3-phase brushless DC motor drives for electric vehicles. International Journal of Automotive Science and Technology, 6(4): 331-339. https://doi.org/10.30939/ijastech.1132500.

[5] Prajapati, K.C., Patel, R., Sagar, R. (2014). Hybrid vehicle: a study on technology. International Journal of Engineering Research & Technology, 3 (12): 1076-1082.

[6] León, R., Montaleza, C., Maldonado, J.L., Véliz, M.T., Jurado, F. (2021). Hybrid electric vehicles: a review of existing configurations and thermodynamic cycles. Thermo, 1 (2): 134-150. https://doi.org/10.3390/thermo1020010

[7] Moawad, A., Rousseau, A. (2012). Effect of Electric Drive Vehicle Technologies on Fuel Efficiency – Final Report. Argonne National Laboratory, Chicago.

[8] Cheng, K.W.E. (2009). Recent development on electric vehicles. 3rd International conference on power electronics systems and applications.

[9] Lalith, D.V., Ghatge, G.C., Setloor, K.G. (2021). Electric and hybrid electric vehicles. International Journal of Research and Analytical Reviews, 8 (4): 76-82.

[10] Sanguesa, J.A., Sanz, V.T., Garrido, P., Martinez, F.J., Barja, J.M.M. (2021). A review on electric vehicles: technologies and challenges. Smart Cities, 4 (1): 372-404. https://doi.org/10.3390/smartcities4010022

[11] Kiyakli, A.O., Solmaz, H. (2018). Modeling of an electric vehicle with matlab/simulink. International Journal of Automotive Science and Technology, 2 (4): 9-15. 10.30939/ijastech..475477

[12] Wang, Z., Zhang, J., Liu, P., Qu, C., Li, X. (2019). Driving cycle construction for electric vehicle based on markov chain and monte carlo method: acase study in Beijing. Energy Procedia, 158: 2494-2499. https://doi.org/10.1016/j.egypro.2019.01.389.

[13] Pfriem1, M., Gauterin, F. (2016). Development of real-world driving cycles for battery electric vehicles. EVS29 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium. 1-11.

[14] Micari, S., Foti, S., Testa, A., De Caro, S., Sergi, F., Andaloro, L., Aloisio, D., Leonardi, S.G., Napoli, G. (2022). Effect of WLTP class 3B driving cycle on lithium-ion battery for electric vehicles. Energies, 15 (8): 1-25. https://doi.org/10.3390/en15186703.

[15] Asef, P., Milan, M., Lapthorn, A., Padmanaban, S. (2021). Future trends and aging analysis of battery energy storage systems for electric vehicles. Sustainability, 13(24): 1-28. https://doi.org/10.3390/su132413779.

[16] Berjoza, D., Pirs, V., Jurgena, I. (2022). Research into the regenerative braking of an electric car in urban driving. World Electric Vehicle Journal, 13(11): 1-13. https://doi.org/10.3390/wevj13110202.

[17] Xu1, Z., Jiang, D., Li, M., Ning, P., Wang, F., Liang, Z. (2012). Si IGBT phase-leg module packaging and cooling design for operation at 200 °C in hybrid electrical vehicle applications. 2012 Twenty-Seventh Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 483-490.

[18] Behi, H., Karimi, D., Youssef, R., Patil, M.S., Mierlo, J.V., Berecibar, M. (2021). Comprehensive passive thermal management systems for electric vehicles. Energies, 14 (13): 1-15. https://doi.org/10.3390/en14133881.

[19] Soltani, M., Ronsmans, J., Jaguemont, J., Mierlo, J.V., Bossche, P.V., Omar, N. (2019). A Three-dimensional thermal model for a commercial lithium-ion capacitor battery pack with non-uniform temperature distribution. 2019 IEEE International Conference on

Industrial Technology (ICIT), 1126-1131. 10.1109/ICIT.2019.8755081.

[20] Behi, H., Karimi, D., Behi, M., Ghanbarpour, M., Jaguemont, J., Sokkeh, M.A., Gandoman, F.H., Berecibar, M., Mierlo, J.V. (2020). A new concept of thermal management system in Li-ion battery using air cooling and heat pipe for electric vehicles. Applied Thermal Engineering, 174: 1-14. https://doi.org/10.1016/j.applthermaleng.2020.115280.

[21] Behi, H., Behi, M., Karimi, D., Jaguemont, J., Ghanbarpour, M., Behnia, M., Berecibar, M., Mierlo, J.V. (2021). Heat pipe air-cooled thermal management system for lithium-ion batteries: High power applications. Applied Thermal Engineering, 183: 1-13. https://doi.org/10.1016/j.applthermaleng.2020.116240.

[22] Al-Zareer, M., Dinçer, I., Rosen, M.A. (2017). Electrochemical modeling and performance evaluation of a new ammonia-based battery thermal management system for electric and hybrid electric vehicles. Electrochimica Acta, 247: 171-182. http://dx.doi.org/10.1016/j.electacta.2017.06.162.

[23] Monika, K., Chakraborty, C., Roy, S., Dinda, S., Singh. S.A., Datta. S.P. (2021). An improved mini-channel based liquid cooling strategy of prismatic LiFePO4 batteries for electric or hybrid vehicles. Journal of Energy Storage, 35: 1-15. https://doi.org/10.1016/j.est.2021.102301

[24] Lu, M., Zhang, X., Ji, J., Xu, X., Zhang, Y. (2020). Research progress on power battery cooling technology for electric vehicles. J. Energy Storage, 27: https://doi.org/10.1016/J.EST.2019.101155.