Simulation of heat dissipation model of lithium-ion battery pack

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Abstract. Lithium-ion power battery has become an important part of power battery. According to the performance and characteristics of lithium-ion power battery, the influence of current common charge and discharge and different cooling methods on battery performance was analysed in this paper. According to the software simulation, in the 5C charge-discharge cycle, the maximum temperature of the cells with regular arrangement is 57.97℃, the maximum temperature of the cells with staggered arrangement is 55.83℃, and the maximum temperature of phase change cooling is 47.42℃. The most important thing is that the temperature difference between the cells with phase change cooling is only 5.5℃. Some simulation results of air cooling and phase change show that phase change cooling can control the heat dissipation and temperature rise of power battery well. The research in this paper can provide better theoretical guidance for the temperature rise, heat transfer and thermal management of automotive power battery.
Keywords: Lithium-ion battery; Temperature; Battery model; Battery pack Model; Air cooling; Phase change cooling.

1 Introduction

As a kind of energy storage equipment, lithium-ion battery has the advantages of energy density, high cycle times, low environmental pollution, low production cost and so on. It involves all fields of production. Yet, As the market for specific energy of batteries is constantly increasing, which is accompanied by the safety problem of batteries. From the chemical level, the battery is constantly undergoing the decomposition of the original material and the generation of new material. It is necessary to ensure the safety of the battery working at the most appropriate temperature. Battery thermal management system as the name suggests is to control the battery in order to battery can work in the appropriate environment, came into being. Start from a practical context, on the premise of considering the cooling cost and efficiency, air cooling, liquid cooling and phase change cooling become the mainstream.

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2 The structure of lithium-ion batteries

To design the battery cooling system, it is necessary to understand the characteristics of the battery, heating location, heat transfer as the premise of research. We above all need to understand the heating principle of the battery. The advantage method was originated from the research of J. Newman et al. [1]. The distance the two ends is 18mm, and the diameter reaches 65mm after the winding is completed and then encapsulated with the shell, and "0" represents the cylindrical structure of the battery. Its axial cross section maybe simplified as Fig1.

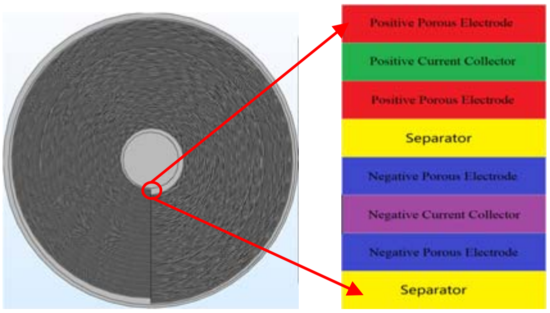

Fig. 1. Axial illustration of a cylindrical battery.

3 Power battery governing equation

In the analysis of the principle of battery heat generation, we must first understand the interior construction of the battery. The heat is contributed by the following parts: the heat of the current under the action of the polarization resistance, the heat of the chemical reaction and caused by the ohmic resistance, and the heat emitted by the formation of the side reaction material. Side reactions caused by lithium deposition in the battery as the number of battery cycles increases and the decomposition of SEI film can be ignored relative to the whole battery heat. Zhang Zhijie et al. [2] used the following formula for the calculation. Lin Guofa et al. [3] studied the battery pack's heat transfer mode, which mainly includes three modes: heat conduction, heat convection and heat radiation.
Polarization heat Q_p: the battery about polarization resistance, J.

$$Q_p = I^2R_p \tag{1}$$

Where, I: current, A; R_p: resistance of polarization, Ω.
Joule heat Q_e: the heat generated by the resistance inside the battery during the working process, J.

$$Q_e = I^2R_e \tag{2}$$

Type: R_e: electronic flow resistance, Ω.
The calorific value of lithium-ion battery is mainly composed of polarization heat and joule heat, J.

$$Q_s = I^2R_t = Q_p+Q_e \tag{3}$$

$$R_t = R_p+R_e \tag{4}$$

$$q_s = I^2R_t/S \tag{5}$$

Type: R_t: internal resistance of battery, Ω. Q_s: Battery heating power per unit area, J. S: Area of heating surface on single battery, m^2.

4 Simulation of battery model

Zhang Junxia [4] takes the heat dissipation management of lithium batteries and lithium battery pack as the primary topic of electric vehicle application. By using computational fluid dynamics simulation analysis method.

This paper selected a brand of lithium manganese acid (LMO) battery. Based on the multi-physical field coupling characteristics of COMSOL. The proposed layered simulation deals with the actual structure state of the battery and defines the physical parameters of each layer structure. After that, three-dimensional model is built, its parameters, and the physical fields of lithium-ion battery and fluid-solid heat transfer are defined. At the same time, flow coupling is called as a multi-physical field. Finally, the grid is divided and the direct solver Pardiso is used for calculation [5]. Electro chemical-thermal model was developed earlier in foreign countries, and the origin of this model can be traced back to 1962. Newman et al. [6] proposed the theory of porous electrode equation to determine the initial and steady conditions of one-dimensional homogeneous porous electrode.

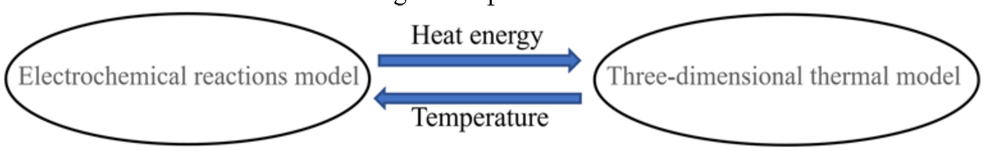

Fig. 2. Temperature interacts with chemical reactions.

Table 1. Basic parameter of the battery.

Parameters	Specification	Parameters	Specification
Cathode material	$LiMn_2O_4$	Charge cut-off voltage	4.35V
Anode material	Graphite	Discharge cut-off voltage	3.67V
Electrolyte	$LiPF_6$	Nominal voltage	4.0V
Nominal capacity	1300mAh	Specific heat capacity	1399.1 J/(kg·K)
Environment temperature	298.15 K	Initial temperature	298.15 K
Paraffin(solid)_K	15W/(m·K)	Paraffin(liquid)_K	0.335 W/(m·K)
Paraffin(solid)_rho	778kg/m^3	Paraffin(liquid)_rho	770 kg/m^3
Paraffin(solid)_Cp	3.2 J/(kg·K)	Paraffin(liquid)_Cp	2.8 J/(kg·K)

Yang et al. [7] studied the series and parallel cooling modes of straight bars and fork bars respectively, and compared and analyzed the effects of transverse and longitudinal spacing on battery temperature. In this paper, COMSOL software is used to simulate the heat dissipation of the battery pack. First, the battery is fully charged from the non-power state and then discharged. The temperature distribution under different heat dissipation methods is recorded in the 1500s for several consecutive cycles.

4.1 Temperature field of staggered battery (ratio of 5C, wind speed of 5m/s)

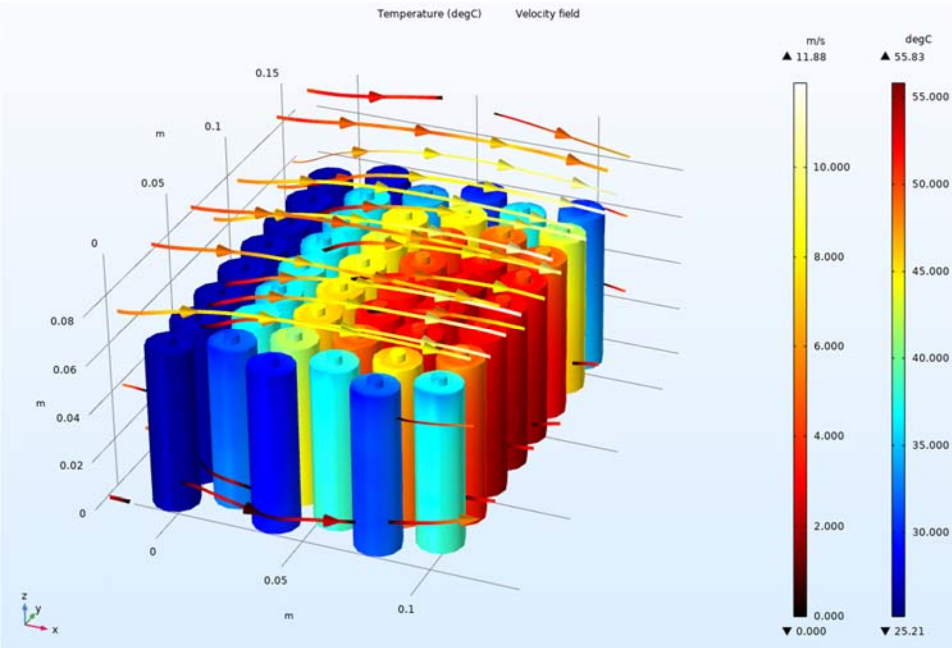

Fig. 3. Cloud map of temperature distribution.

4.2 Regular battery temperature field (ratio of 5C, wind speed of 5m/s)

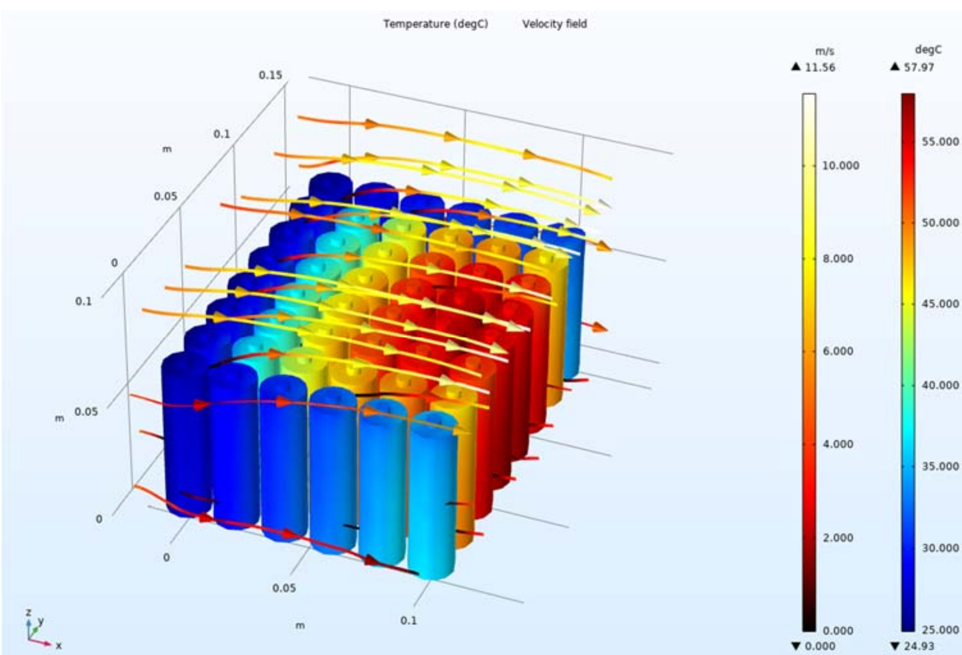

Fig. 4. Cloud map of temperature distribution.

The battery pack with regular arrangement is used. In the whole battery pack, the cloud image showed that the temperature in the back row reached 57.97℃ while that in the front row was 24.93℃, with a difference of 33.04℃ before and after. Contrast to that with an alternating structure, the same windward area and the same airflow velocity were used. As a result, the vertex of temperature reflected in the cloud map is 55.83℃ and the lower limit reached 25.21℃, with a difference of 30.62℃.

The results show that the staggered arrangement is more conducive to heat dissipation, avoiding the shielding of the airflow by the battery, to improve the heat dissipation, it is more important to control the uniformity of the heat dissipation mode, so that there will not be a large difference.

4.3 Phase change cooling method (charge and discharge ratio of 5C)

In 2013, Cao Jianhua [8] from Tsinghua University studied the battery thermal management technology of automotive lithium-ion battery based on phase change materials, using paraffin wax as phase change material. In this paper, the solid paraffin was set as a liquid with a temperature of 301.15K and a latent heat of 220000J /kg.

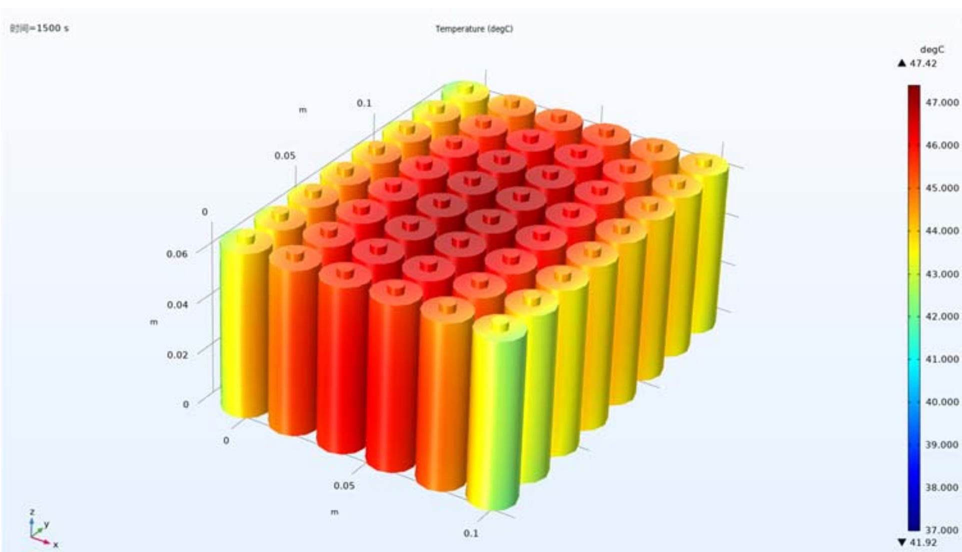

Fig. 5. Cloud map of temperature distribution.

Temperature limits of the battery are 47.42℃ and 41.92℃ respectively, interpolation controlled at 5.5℃. The heat inside the battery pack is difficult to emit to the outside world, and is affected by the thermal radiation from the surrounding areas, resulting in heat concentration.

5 Simulation results and deficiencies

Simulation results :

(1) Battery arrangement, such as staggered contrast regular arrangement, has a linkage effect on the temperature of the battery, interleaved arrangement recommended.

(2) the use of paraffin phase change cooling battery, battery temperature change control is better than air cooling, at the same time, but the paraffin itself increases the weight of the body, affecting the vehicle range.

Shortages:

(1) The conditions of model construction are relatively simple.

(2) The cycle is regular, so it is more referential to select loads under varying working conditions for calculation or the mileage test spectrum of national electric vehicles.

(3) Experiments at different external temperatures can be simulated according to seasonal or regional differences.

6 Conclusion

Combined with the above simulation results, it can be concluded that the battery layout directly affects the battery temperature. Under same conditions, the effect of staggered battery arrangement is better, but the temperature difference between the batteries is still large. Using phase change cooling provides the best control over battery temperature and Temperature differences, but it is more expensive than air cooling and adds weight. It is suggested that the battery layout should be staggered under the premise of permitting the body layout. If the cost of the vehicle permits, the use of phase change cooling can better control the temperature difference of the battery, more ensure safety.

References

1. Doyle, J. Newman, A.S. Gozdz, C.N. Schmutz, and J.M. Tarascon. Comparison of Modeling Predictions with Experimental Data from Plastic Lithium-ion Cells. J. Electrochem. Soc. **143**(6):1890–1903, (1996).
2. Zhang Zhijie, Li Maode. Research on Temperature Rise Characteristics of Lithium-ion Power Battery [J]. Automotive Engineering, (2010), **32**(04):320-321.
3. Lin Guofa. Research on Temperature Field and Optimization of Heat Dissipation Structure of Lithium Battery Packs for Pure Electric Vehicles [D]. Chongqing University, (2011).
4. ZHANG Junxia. Thermal Characteristics Analysis and Optimization Design of Power Battery Packs for Electric Vehicles [D]. Tianjin University of Science and Technology, (2018).
5. Lin Hao, Zhang Hongxin, Zhao Qinghai. Three-dimensional Electro-chemic-thermal Coupling Model and Thermal Generation Analysis of Lithium-ion Batteries [J]. Power Supply Technology, (2019), **43**(10), 1630-1632.
6. Newman J S, Tobias C W. Theoretical analysis of current distribution in porous electrodes[J]. Journal of The Electrochemical Society, 1962, 109(12): 1183-1191.
7. Yang N, hang X, Li G, et al. Assessment of the forced air-cooling performance for cylindrical lithium-ion battery packs: A comparative analysis between aligned and staggered cell arrangements[J]. Applied Thermal Engineering, 2015, 80:55-65.
8. CAO Jianhua. Research on Thermal Management System of Lithium-ion Battery Based on Phase Change Materials [D]. Tsinghua University, (2013).