

Analysis of Heat Dissipation of Lithium Battery Pack Based on Eddy Current Tube

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Abstract: In this study, numerical heat dissipation simulation is carried out using vortex tube heat dissipation technique for the heat dissipation problem of lithium batteries. First of all, the type of lithium battery, thermal runaway phenomenon, thermal runaway temperature range, and then the lithium battery group cooling methods and advantages and disadvantages of the exposition; followed by the working principle of eddy current tube, the application of the way, as well as the advantages and disadvantages of the exposition. Combined with the vortex tube's own structural characteristics, numerical simulation is used to apply the vortex tube cooling to lithium battery heat dissipation. This study provides new ideas and methods for the development of lithium battery heat dissipation technology, and has important reference value for solving the heat dissipation problems of lithium battery in practical applications.

Keywords: Vortex tube; Lithium batteries; Heat dissipation.

1. Introduction

With the rapid development of science and technology and the promotion and application of green energy, lithium batteries are in increasing demand due to their advantages of high energy density, long cycle life and environmental friendliness. In many fields, such as portable electronic products, electric vehicles, and solar and wind energy storage systems, lithium batteries are becoming an indispensable source of energy supply, bringing convenient and sustainable development to human society. At present, the main lithium batteries used are: nickel-cobalt-manganese (NCM) ternary material batteries, nickel-cobalt-aluminium (NCA), lithium titanate (LTO) batteries, lithium iron phosphate (LFP) batteries; due to the fact that lithium iron phosphate (LFP) batteries have a stable olivine-type crystal structure and do not contain cobalt and other precious metals, making the manufacturing cost is lower, reducing the lithium batteries in the process of decomposition of the environment caused by the pollution in the over-charge, Overcharge, discharge, short-circuit and other abnormal conditions, has a better thermal stability, in the case of overcharge, overdischarge, lithium ions can be stably embedded and disengaged, to avoid the rapid generation of a large amount of heat in the process of chemical reaction, thus improving the safety of the battery. Lithium batteries generally have a normal operating temperature range of -20~65°C [1].

In the use of the battery to avoid thermal runaway, if the battery thermal runaway will produce the following results: 1, battery corrosion or cracking; 2, battery bulging; 3, battery fire combustion; 4, rapid generation of gases and smoke; 5, leakage of electrolyte corrosion of the surrounding equipment; these situations will seriously affect the safety of the user, so we need to try our best to avoid the domestic and foreign thermal runaway lithium batteries temperature main Research has: nickel-cobalt-manganese (NCM) ternary material batteries, thermal runaway temperature range is 170-200 °C; nickel-cobalt-aluminium (NCA) and lithium titanate (LTO) batteries, 171 °C or so; lithium iron phosphate (LFP) batteries,

264-280 °C or so [2-6]. Because the lithium iron phosphate (LFP) battery has a stable olivine-type crystal structure and does not contain precious metals such as cobalt, which makes the manufacturing cost lower and the environmental pollution caused by lithium batteries in the decomposition process is small. It has better thermal stability under abnormal conditions such as overcharging, overdischarging and short-circuiting. In the case of overcharging and overdischarging, lithium ions can be stably embedded and dislodged, avoiding a large amount of heat being generated rapidly during the chemical reaction, thus improving the safety of the battery. Because of the above advantages, it is widely used in the new energy automobile industry. In order to ensure the normal use in daily life and prevent the occurrence of thermal runaway phenomenon due to accelerated aging of the battery, it is very necessary to adopt heat dissipation and cooling for lithium batteries. At present, the main cooling methods used are: air cooling, liquid cooling, phase change material cooling (PCM), heat pipe cooling, and the former single cooling method for the composite cooling method that is the composite cooling [7]; the existing air cooling, liquid cooling, PCM cooling and heat pipe cooling, although the cooling effect is relatively good, but due to the need to increase the cooling system of liquid pumps, fans, and high cost of cooling medium and the cooling system. Because the liquid pump and fan are moving parts have a certain failure rate, so the vortex tube, which has no moving parts and better cooling effect, is used to study the heat dissipation effect on lithium batteries. The vortex tube uses a nozzle to introduce the compressed gas into the vortex chamber, and through the energy separation effect, the airflow is separated into parts with different temperatures, so as to achieve the effect of cooling or heating [8]. Because of its simple structure and no moving parts so it is used in food, electronic components manufacturing, machinery precision manufacturing and natural gas transmission. The vortex tube generally consists of inlet nozzle, vortex chamber, cold end orifice, hot end control valve and hot and cold end tubes [9]. Therefore, in summary, the significance of using vortex tubes to analyse the impact of heat dissipation on lithium battery packs lies in the absence of complex moving parts, the use of

simple vortex tubes so that the failure rate of the cooling system is reduced as well as the use of the fluid itself in the flow channel using vortex to carry out energy separation without pollutants, and more environmentally friendly. Used for lithium battery cooling, you can use its temperature adjustable characteristics of the lithium battery pack to effectively dissipate heat and avoid excessive energy loss. Can effectively reduce the overall quality of lithium battery packs in the use of the process, reduce the manufacturing cost of heat dissipation devices.

2. Modelling

2.1. Physical Modelling

Figure 1 is the 18650 type lithium iron phosphate battery pack solid domain, using array form arrangement, due to the lithium battery positive and negative electrodes have a relatively small structure, but not much impact on the heat transfer, for this reason on the lithium battery to simplify and simplified lithium battery single size for the diameter of the

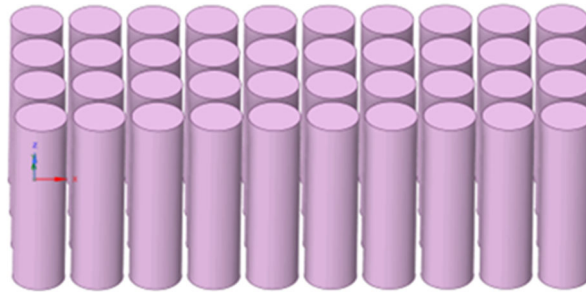


Figure 1. Solid domain of 18650 lithium iron phosphate battery packs

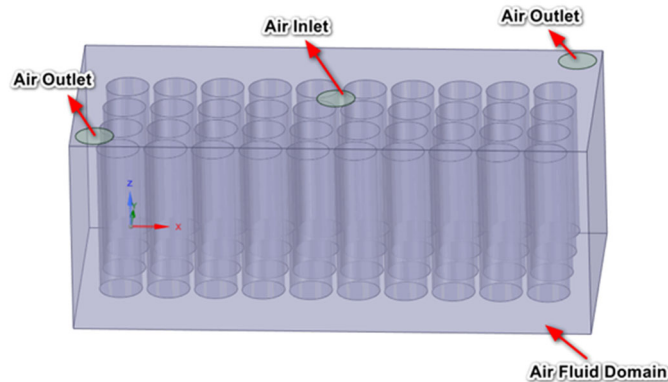


Figure 2. Fluid domain model of 18650 Li-ion battery packs

2.2. Calculation Model and Assumptions for Lithium Battery Heat Generation

As the internal chemical reaction and structure of lithium iron phosphate battery is more complex, in which the chemical reaction will produce a large amount of heat, so in practice, for easy calculation, in the normal working cycle of lithium battery, the total heat production of lithium battery Q_t is divided into four parts: Joule heat Q_J , heat of chemical reaction Q_C , heat of side reaction Q_F and heat of polarisation Q_P .

$$Q_t = Q_J + Q_C + Q_F + Q_P \quad (1)$$

mm, the height of the $h = 65$ mm. Figure 2 is based on Figure 1 will be the lithium battery pack vortex tube air-cooled domain is created, in which there is an inlet and two outlets. The cells are evenly spaced at 2 mm intervals, and the entire battery pack model is meshed using Fluent Meshing with approximately 254795 grid cells. 2.2 Page Numbers.

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Where the heat of chemical reaction Q_C is the heat change caused by the chemical reaction of lithium ions in lithium batteries during charging and discharging, charging is negative and discharging is positive, Q_C can be expressed as:

$$Q_C = \frac{nmQI}{MF} \quad (2)$$

Where, n-number of single cells; m-mass of positive and negative electrodes; Q -algebraic sum of heat production from chemical reactions occurring at both levels of the cell; $I(A)$ -magnitude of current for charging and discharging; $M(g/mol)$ -molar mass; F -Faraday's constant, which has a value of 96485.3C/mol.

The main reason for the existence of Joule heat Q_J is due to the existence of internal resistance of lithium batteries, when

there is a current through the battery, heat will be generated and the generation of heat is irreversible, in the process of charging and discharging the value of positive, Q_J expression is as follows:

$$Q_J = I^2 R_e \quad (3)$$

Where, I denotes current intensity, A; R_e - battery internal resistance, Ω .

The heat of side reaction Q_F refers to the heat of electrochemical reaction that occurs in the process of battery use, such as the decomposition reaction of electrode and electrolyte, but since the heat of side reaction Q_F is small in the whole charging and discharging process, it can be ignored.

Heat of Polarisation Q_P is the heat production of the electrode polarisation process. Electrode polarisation is a phenomenon in which the electrode potential deviates from the equilibrium potential when a current is passed through the electrode. It is divided into anodic polarisation and cathodic polarisation, which cause the anodic potential to become more positive and the cathodic potential to become more negative, respectively. The heat production caused by the reduction in pressure difference due to the existence of a gap in the terminal voltage of the cell is known as the heat of polarisation.

It is very difficult to obtain accurate battery heat production in practice, and the mainstream methods are theoretical calculations and experimental analyses. This numerical simulation study, on the other hand, is based on the theoretical formula calculation method using fluent software for UDF battery source term loading [9].

Bernadi, University of California, assumes that the heat inside the battery is uniformly distributed, takes the internal resistance of the battery and the entropy increase reaction as the basis of the study, and the battery steadily generates heat, establishes a numerical model for calculating the heat generated by the battery, and proposes theoretical formulas for the calculation:

$$Q = \frac{I}{V_b} \left((U - U_0) + T \frac{dU_0}{dT} \right) = \frac{I}{V_b} \left(I^2 R_r + T \frac{dU_0}{dT} \right) \quad (4)$$

Where, Q - the rate of heat generation per unit volume inside the battery, J/m³ s; I - the charge and discharge current of the battery, positive for charging and negative for discharging, A; V_b - the total volume of the battery, m³; U - the battery voltage of the battery, i.e., the open-circuit voltage, V; U_0 the operating voltage, V; T - temperature of the battery, K; R_r - equivalent internal resistance of the battery, Ω ;

$\frac{dU_0}{dT}$ - Temperature influence coefficient, which varies

with the operating voltage of the battery;

$I^2 R_r$ - Joule heat and heat of polarisation sections;

$T \frac{dU_0}{dT}$ - reaction heat component, but in practical

calculations, this heat is such a small percentage of the total heat generation that it can be simplified and ignored [10].

Due to the more complex structure and materials within the lithium iron phosphate battery, there are more ways to exchange heat in the process of charging and discharging, so it is necessary to simplify the assumptions on the thermal conductivity coefficient when calculating its thermal conductivity, and the following simplified assumptions are made on the thermal model of lithium batteries:

1, assuming that the battery core is a single entity and there is no convective heat transfer inside, only the convective heat transfer between the outer surface of the battery and the external environment is considered;

2. By Bernadi's formula, the heat inside the battery is assumed to be uniformly distributed and the heat production inside the battery is stable;

3. In the numerical simulations, it is assumed that the thermophysical parameters of the materials of interest are all constants.

18650 lithium iron phosphate battery heat transfer is divided into two stages, the first stage for the battery pack to the air domain part, the second stage for the air domain part to the external environment, first, the battery pack to the air domain part, this part belongs to the fluent in the coupled wall heat transfer, which includes both heat conduction and heat convection; second, the air domain part to the external environment, which belongs to the heat convection heat transfer mode, due to the two alternating effects, making a very complex heat exchange process between the battery and the air domain. Due to the simplification of the external solid domain covered by the air domain, we mainly study the numerical simulation of heat dissipation of the lithium battery pack and the air domain part.

3. Boundary Conditions and Assumptions

In terms of heat production boundary conditions are divided into two kinds, the first is the lithium battery pack in the confined space and no flowing air working environment for discharge heat transfer simulation, at this time the air heat transfer can be negligible. The second is in the vortex tube cold end outlet temperature of 2.85 °C, the flow rate of 5m / s air, lithium battery pack were in the above two boundary conditions, respectively, with 0.5A, 1A, 2A, 3A current for 1h of work. As the 3A working current is not effective to be cooled by using air with a flow rate of 5m/s, the flow rate is adjusted to 10m/s for cooling, and the battery is able to work stably in the normal working temperature range.

The boundary condition in terms of heat dissipation is based on the second boundary condition in terms of heat production boundary condition, which establishes the heat transfer boundary condition between the air domain and the external simplified solid domain.

In the numerical simulations, the following assumptions are made:

1. Using the flow rate and temperature parameters of the cold end outlet of the vortex tube, the physical modelling of the vortex tube is omitted;

2. Omit and simplify the positive electrode part of the solid domain model of 18650 type lithium battery;

3. Omit and simplify the solid domain part of the external shell of the lithium battery pack, and do not consider the heat exchange between the lithium battery shell and the outside air.

The 18650 lithium iron phosphate battery uses lithium iron phosphate material as the positive electrode material and graphite material as the negative electrode material. The

geometric and thermal material performance parameters of the battery and air medium are shown in Table 1 and Table 2.

Table 1. Geometric and thermophysical performance parameters of the cell

	geometric parameter (mm)	density (Kg•m ⁻³)	thermal conductivity (W/m/K)	specific heat capacity (J/kg/K)
Length (X)	18		2.8	
Width (Y)	18	2700	2.8	970
High (Z)	65		28	

Table 2. Physical parameters of air medium

	Geometric parameters of the air domain (mm)	density (Kg•m ⁻³)	thermal conductivity (W/m/K)	specific heat capacity (J/Kg/K)
Length (X)	218			
Width (Y)	98			
High (Z)	85	1.225	5	1006.43
Inlet Diameter	16			
Outlet Diameter	16			

The simulation analysis parameters are set as follows: inlet air temperature is 2.85°C, inlet condition is velocity-inlet, initial velocity is 5 m/s, Reynolds number at the air inlet is 1e5, and turbulence model and pressure outlet are selected for the solution, in which the computational domain consists of the air domain and the cell-solid domain, and the wall is calculated using the standard wall function method, and the flow-solid coupling heat transfer is carried out in the air and the cell-solid domain, and forced convection is carried out outside the air domain, and the convection heat transfer coefficient is 5 W/(m K). The air domain and the cell solid domain carry out fluid-solid coupling heat transfer, and the forced convection is carried out outside the air domain, and the convection heat transfer coefficient is 5W/(m² K).

is 13.02°C, the temperature cloud shows that the temperature of the middle battery is at the bottom, and the temperature of the battery close to the two ends of the wall is higher, but lower than the temperature at which thermal runaway occurs, so the wind speed of 10m/s is adopted to conduct 1h heat dissipation simulation for the battery pack with an operating current of 3A battery pack to take the same boundary conditions for 1h heat dissipation simulation, the results are shown in Figure 3, Figure 4 and Figure 5, the maximum temperature of the battery pack is 47.02 °C, with no vortex tube cooling when the temperature difference is 38.64 °C, near the entrance of the wind speed is larger, and the battery coupled heat transfer can take away more heat, the higher temperature of the battery due to the exit of the diagonal arrangement, resulting in a higher temperature location of the air volume Higher temperature battery due to the diagonal arrangement of the outlet, resulting in higher temperature location of the air volume and wind speed is smaller, the heat transfer effect is reduced, but the use of vortex tube on the lithium battery pack heat dissipation, the effect is more significant and work reliably.

4. Analysis of Simulation Results

The temperature cloud of the battery pack at the maximum operating current of 3A is shown in Fig. 1 and Fig. 2, the maximum temperature of the battery pack is 72.64°C, and the temperature difference with that without vortex tube cooling

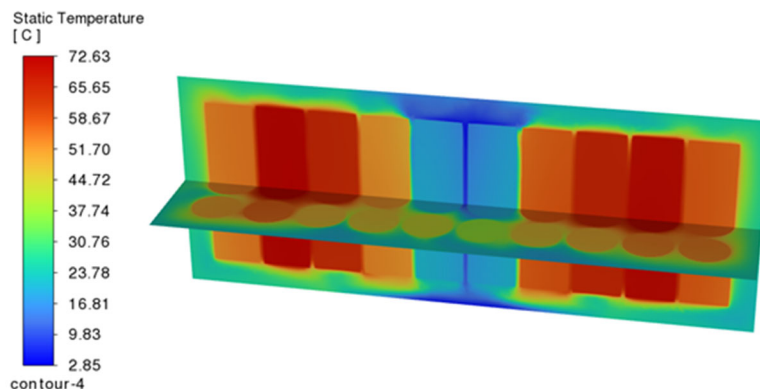


Figure 1. V=5m/s 3A Li-ion battery pack cooling cross-section temperature

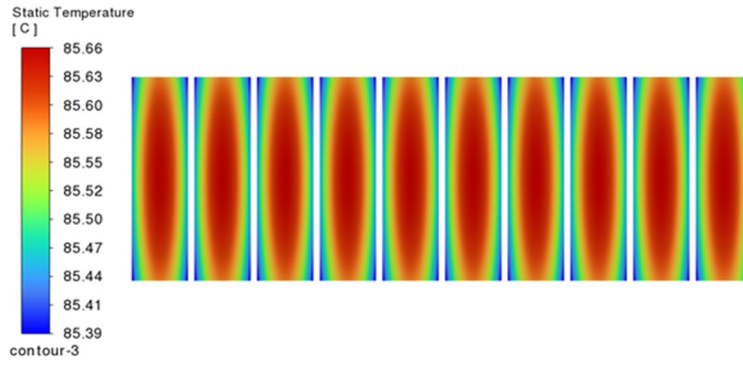


Figure 2. 3A Uncooled temperature

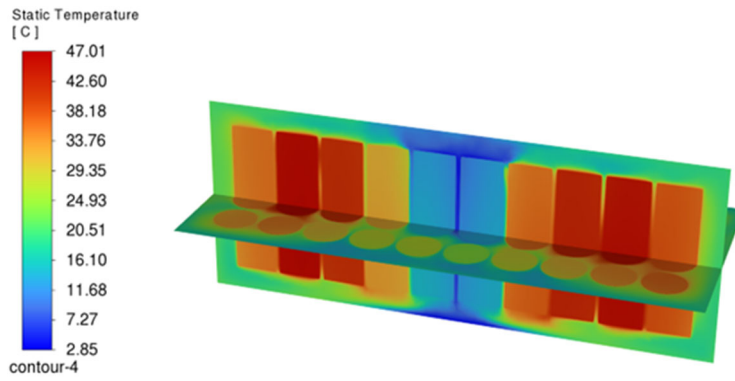


Figure 3. Temperature cloud of $V=10\text{m/s}$ 3A lithium battery pack cooling cross-section diagram

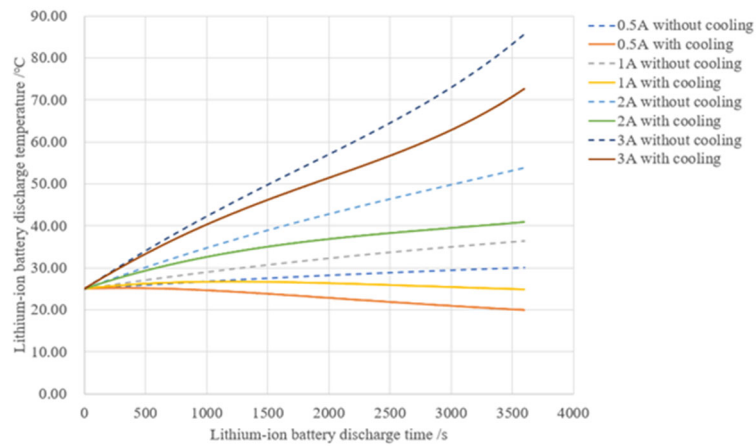


Figure 4. Comparison before and after cooling of vortex tube

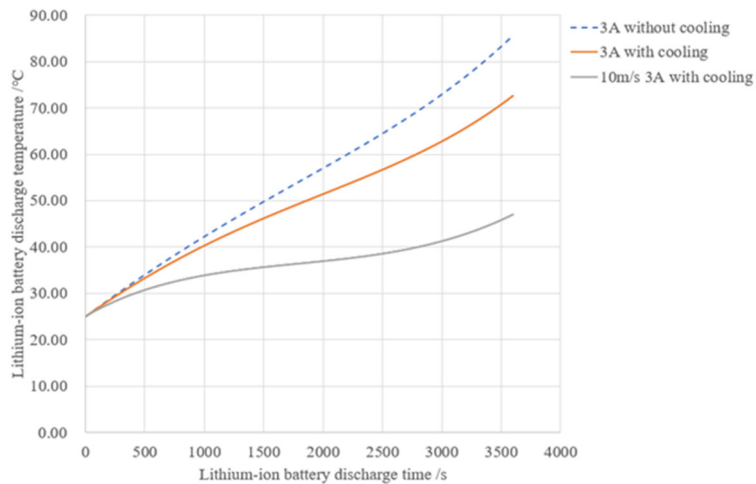


Figure 5. Comparison of $V=10\text{m/s}$ and 5m/s 3A cell temperature

5. Summary

The analysis and study of vortex tube in the application of lithium battery heat dissipation provides a new perspective to solve the problem of lithium battery heat dissipation. As an effective means of heat dissipation, computational fluid dynamics and heat transfer methods are used to model and numerically calculate the air-cooled heat dissipation of lithium battery packs based on vortex tubes. The cold air at the cold port of the vortex tube is used to promote the heat transfer and dissipation of the battery pack, effectively reducing the operating temperature of the lithium battery and prolonging its service life. The design and optimisation of the vortex tube plays a key role in improving the heat dissipation performance of lithium batteries. Simulation results show that the use of vortex tube for lithium battery pack heat dissipation can reduce the heating temperature of lithium battery discharge to within the normal operating temperature range, and can adjust the temperature and speed of the vortex tube cold end outlet to meet the needs of different lithium battery pack heat dissipation. At the same time, as an emerging heat dissipation technology, eddy current tubes still need to overcome some challenges in practical applications, such as how to ensure its stability in high temperature and high pressure environments, as well as how to improve its heat dissipation efficiency and other issues. In summary, the heat dissipation technology of lithium battery based on eddy current tube has great research value and application potential. In order to achieve more efficient heat dissipation and longer service life of lithium batteries, in-depth research and optimisation of vortex tubes are required.

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