ANALYSIS AND OPTIMIZATION CONTROL OF FINNED HEAT DISSIPATION PERFORMANCE FOR AUTOMOBILE POWER LITHIUM BATTERY PACK

by

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To cope with the problem of global warming and improve the performance of electric vehicles, the power source of electric vehicles is researched. First, the CFD simulation analysis method is utilized to analyze the heat dissipation effect under the changes of the air intake speed, the number of fins, and the thickness of the fins between lithium batteries. Then, the orthogonal experiment is utilized to select the optimal solution between the lithium batteries. The simulation results show that the heat dissipation effect is optimal under the conditions that the inlet air speed is 8 m/s, the number of fins is seven, and the thickness of fins is 2.5 mm. Then, the orthogonal experiment determines the optimal heat dissipation scheme of the lithium battery pack the air inlet speed is 8 m/s, the number of fins is six, and the thickness of the fins is 2 mm. This optimal scheme can effectively improve the heat dissipation performance of lithium batteries, enhance the performance of electric vehicles, and reduce CO_2 emissions.

Key words: *lithium battery, finned heat exchanger, thermal management system, heat dissipation performance*

Introduction

In recent years, the environmental awareness of people has been continuously strengthened. For energy conservation and emission reduction, as well as reducing air pollution, the demand for electric vehicles (EV) has been increasing. Generally, the materials of power source batteries for EV are lithium batteries. To improve the performance of lithium batteries, scholars have studied the structural performance parameters of lithium batteries. The thermal management system equipped in the lithium battery controls the battery to work normally within a certain temperature range, thereby ensuring the service life of the lithium battery [1]. Thermal management systems for lithium batteries can be divided into four categories, *i. e.*, air cooling, liquid cooling, heat pipe cooling, and phase change materials. To ensure that the lithium battery can dissipate heat normally, a heat transfer medium is required, which can be divided into two types, *i. e.*, the medium that directly contacts with the surface of the lithium battery, and the medium that indirectly contacts with the surface of the lithium battery [2]. Scholars have calculated the heat dissipation performance of lithium batteries through fluid

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dynamics and found a cooling plate channel containing a coolant, which has been applied to the high-energy battery cooling system in EV [3]. Some scholars have proposed the utilization of a cooling plate method with liquid-flowing obliquely to solve the problem of large temperature difference between the battery packs. At the same time, they also studied the tube diameter inside the cooling plate and the angle of liquid-flow [4]. When the phase change material cools the lithium battery, the temperature of the lithium battery rises to the phase change temperature, and these phase change materials will change their current form from solid to liquid to achieve the purpose of absorbing the heat generated by the lithium battery. However, the low phase change temperature of phase change materials has limited its application in lithium battery heat dissipation systems. Meanwhile, the structure of this type of thermal management system and heat pipe cooling method is complicated [5].

In China, most of the existing thermal management studies of lithium battery packs (LBP) in EV tend to design complex bellows structures, heat pipe structures with added liquid cooling cycles, or use phase change materials to achieve thermal management of LBP [6]. Under certain measurement standards, the maximum temperature increase range of the lithium battery during work and the temperature difference between the lithium battery cells have indeed improved to some extent. However, in this thermal management model, it is common in thermal management systems that the heat dissipation structure is complicated, and the arrangement method between the heat dissipation structure and the LBP cannot be closely combined, which causes problems such as inconvenience in production, manufacturing, and processing [7]. Research on the optimization design of heat dissipation structure in China is still in the period of software simulation.

This study has applied a finned heat exchanger (FHE) to the heat dissipation structure of a LBP. The CFD simulation analysis method is used to calculate the heat dissipation performance of the LBP. The COMSOL Multiphysics simulation software is selected to analyze several factors, such as the air intake speed, the number of fins, and the thickness of the individual fins that affect the heat dissipation performance of the LBP. The orthogonal analysis method selects the best optimization scheme for the heat dissipation performance of the LBP.

Methods

The FHE

The FHE is usually composed of a partition, a fin, a seal, and a deflector. In terms of its heat transfer mechanism, the FHE belongs to the shoulder-arm heat exchanger [8]. The FHE has the characteristics of the fin surface for secondary heat transfer, thus, it can carry out the expansion of the heat transfer process. Therefore, when the FHE is used for thermal management of the LBP, the FHE heat transfer process is not only performed on the heat transfer surface and its separator but also the surface of the fins, which ultimately improves the heat transfer efficiency [9]. Moreover, when using the FHE for thermal management, the direction of transmission of high temperature to low temperature can extend from the thickness direction of the fins to the height direction of the fins [10]. The fin height of the FHE is much larger than the fin thickness. Therefore, the heat transfer process of the FHE along the height direction of the fin has high similar characteristics to the heat transfer process of the slender guide rod. Therefore, the heat resistance of the fins must be considered when working with FHE. The highest temperature that can be reached at both ends of the fin is equal to the temperature of the separator. As the convective heat dissipation process of the fin and the medium continues, its temperature will continue to decrease until it reaches a relative thermal equilibrium with the medium [11].

Parameter setting for COMSOL multiphysics simulation analysis

In considering the use of FHE to dissipate lithium batteries, the convection heat transfer mode of the FHE is mainly considered, and the concept of air domain is added to the analysis of them. In the analysis, the discharge rate of the LBP is selected to be 1c, (1-fold rate, which indicates that the battery is fully discharged in one hour), and the temperature change of the LBP under this working efficiency is used as the analysis factor [12]. The CFD simulation analysis method is selected as the simulation analysis calculation method for this experiment, and the COMSOL Multiphysics software is used to improve the computational efficiency of CFD. Thus, it is used as the CFD simulation software. This study mainly considers the inlet air speed, inlet air temperature, the distance between the battery pack and the air inlet and outlet, the number of fins, and the thickness of the fins, which mainly affect the heat dissipation efficiency of the LBP. The single-factor variable analysis method is used to optimize the design of the heat dissipation structure of the LBP.

In the simulation, it is necessary to input the geometric parameters of the lithium battery, that is, the actual air intake speed of the lithium battery, the temperature of the air intake, the distance between the battery pack and the air inlet and outlet, the number of fins, and the thickness of the fins [13].

Optimization of inlet speed parameters

First, the outflow direction of the LBP is taken as an example, the distance between the individual cells is taken as a quantity, and the intake air-flow rate is taken as a variable. In this case, the speed of the intake air-flow of the LBP is increased, and the lithium battery is improved by this method. The air speed in the channels between the single cells improves the heat dissipation efficiency of the LBP [14]. When using CFD simulation analysis method to simulate the heat dissipation performance between LBP, it is necessary to first enter the air domain and the matrix parameters of the LBP, the geometric parameters of the fin heat exchanger, and each parameter setting in the COMSOL Multiphysics simulation software, as shown in tab. 1.

Table 1. Optimized parameter setting of inlet speed

Name	Parameter setting			
Fin geometric	Height	Thickness	Number of fins	Heat sink type
	5 cm	1 mm	5	Straight
Box	Inlet distance	Outlet distance	Lateral distance	Top distance
	6 cm	10 cm	0.5 cm	0.5 cm
Operating conditions	Inlet speed	Inlet temperature	Heat source temperature	
	8 cm/s	22 °C	48 °C	

After inputting the parameters for modelling, it is also necessary to mesh these parameters, and finally to perform simulation calculations. The simulation calculations should be performed under the condition that the wind speeds are 2/4/6/8. This step needs to be repeated four times in total.

Parameter optimization of FHE

First, the outflow direction of the LBP is taken as an example, the distance between the individual cells is taken as a quantity, and the intake air-flow rate is taken as a variable. In this case, the speed of the intake air-flow of the LBP is increased, and the lithium battery is improved by this method. The air speed in the channels between the single cells improves the heat dissipation efficiency of the LBP [15]. When using CFD simulation analysis method for simulation calculation, it is necessary to need air domain and the matrix parameters of the LBP, the geometric parameters of the fin heat exchanger, and each parameter setting in the COMSOL Multiphysics simulation software, as shown in tab. 2.

Table 2. Optimized parameter setting of FHE number

Name	Parameter setting			
Fin geometric	Height	Thickness	Number of fins	Heat sink type
	5 cm	1 mm	3/5/7	Straight
Box	Inlet distance	Outlet distance	Lateral distance	Top distance
	6cm	10 cm	0.5 cm	0.5 cm
Operating conditions	Inlet speed	Inlet temperature	Heat source temperature	
	8 cm/s	22 °C	48 °C	

After inputting the parameters for modelling, it is also necessary to mesh these parameters, and finally to perform simulation calculations. The simulation calculations should be performed under the condition that the number of FHE is 3/5/7. Since in the previous step, the simulation analysis result when the number of fins is seven is already available, it is not necessary to perform a simulation analysis again. Therefore, this step needs to be repeated two times.

Optimized parameters of individual fin thickness of FHE

First, based on the air intake speed of the LBP and the distance between the individual cells as a quantity, the number of fins of the FHE is still a variable. In this case, the individual fin thickness of the FHE of the LBP is increased. At the same time, the number of FHE is changed. Due to the space limitation between LBP, when the individual fin thickness is increased to 2.5 mm, the space can only accommodate up to six fins [16]. Therefore, the maximum number of fins in this simulation is six. Through this method, the heat radiation efficiency of the air in the thermal management system is improved, and finally the heat radiation efficiency of the LBP is improved. Also, when using the CFD simulation analysis method for analysis, the basic parameters of the air domain and LBP and the geometric parameters of the FHE need to be input into the COMSOL Multiphysics software, and the parameter settings are shown in tab. 3.

Table 3. Optimized parameter setting of individual fin thickness of FHE

Name	Parameter setting			
Fin geometric	Height	Thickness	Number of fins	Heat sink type
	5 cm	2.5 mm	3/5/6	Straight
Box	Inlet distance	Outlet distance	Lateral distance	Top distance
	6 cm	10 cm	0.5 cm	0.5 cm
Operating conditions	Inlet speed	Inlet temperature	Heat source temperature	
	8 cm/s	22 °C	48 °C	

After inputting the parameters into the software, they are then meshed, and finally they are simulated. The difference between this experimental analysis and the previous step of fin number optimization is to increase the thickness of the FHE to 2.5 mm. For simulation calculations, this step needs to be repeated three times in total.

Design of orthogonal experiment

Through orthogonal experiment (OE) analysis of three factors affecting the heat dissipation structure, *i. e.*, the air intake speed, the number of fins, and the thickness of the fins, the fins are finally obtained at an air intake speed of 2/4/6/8, the number of fins is 3/5/6, and the analysis is performed with an individual fin thickness of 1/2/2.5. If the OE is carried out according to the aforementioned scheme, a total of 27 simulation analyses are required. Many of the simulation analysis parameters are repeated and unnecessary. Therefore, it is necessary to simplify the scheme, reduce the workload, and enable the test process to make the effective analysis results obtained with a limited number of experiments. Therefore, the OE is simplified according to the orthogonal test analysis scheme of L_9 (3^4) [17]. The simplified test scheme uses single factor air speed of 2/6/8, and the number of fins is 3/5/6. Experiments are performed with fin thicknesses of 1/2/2.5 as variables, and only one experiment is required in each case to obtain the optimal optimization plan.

Results and analysis

Simulation results of air inlet speed

The COMSOL multiphysics software is used to simulate the heat dissipation effect of LBP at different air intake speeds. It is found that when the air intake speed between LBP is 6 m/s, the maximum temperature of the LBP has reached only 24.5 °C, with a temperature difference range of 2 °C. When the air inlet speed reaches 8 m/s, the maximum temperature of the LBP drops to 24 °C, and the temperature difference range decreases to 1.5 °C. Since the space size of the LBP is fixed and limited, the air intake speed will continue to increase. When it is greater than 8 m/s, the maximum temperature of the LBP will not decrease any more. However, due to the increase of the air intake speed, the air pressure in the air intake area ofthe LBP will be increased to an extremely high level, which will be detrimental to the air entering between the LBP. In the end, the pressure of the air-flow between the LBP will be too large, and the temperature difference between the LBP will not be obvious. Therefore, when the inlet air speed between the LBP is 8 m/s, the maximum temperature and temperature difference between the LBP are low. Therefore, analysis by COMSOL multiphysics simulation software shows that when the distance between the air intake area and the air inlet of the LBP is 6 cm, and when the lithium battery cells are distributed at an equal distance, the air intake speed between the LBP is 8 m/s, the maximum temperature and temperature difference of the battery packs are low, and the heat dissipation effect between the LBP is good. The analysis results using COMSOL Multiphysics simulation software are shown in fig. 1. When plotting this figure, 300 W is set as the standard for the heat dissipation performance of the LBP. The heat dissipation performance and standard values of the LBP at different air inlet speeds are utilized for comparison, and the influence of the inlet air speed on the heat dissipation performance of the LBP is measured.

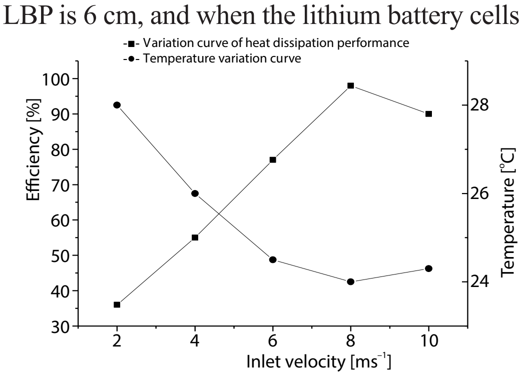

Figure 1. Simulation analysis of the heat dissipation performance of the LBP when the inlet air speed changes

Also, as shown in fig. 1, when the air intake speed between the LBP is 8 m/s, the maximum temperature and temperature difference of the battery packs are both lower since the air speed in the flow path between the fins is higher and has better uniformity at this time.

Simulation results of the fin number of FHE

After the LBP are radiated through the FHE, the temperature between the LBP is also reduced to 25 °C, so that the temperature range of the lithium batteries during operation falls within a temperature range close to normal temperature. In the previous step, when studying the air inlet speed, the number of fins between the LBP has been set to seven, and when the air inlet speed is 8 m/s, the analysis results of simulation have been obtained. When the air inlet speed is 8 m/s, the simulations are performed for the case where the number of FHE is 3 and 5, respectively. By comparison, when the number of FHE is 7, the maximum temperature between LBP and the temperature difference range between LBP are the lowest. As the number of FHE continues to increase, the cross-sectional area of heat dissipation between LBP also increases; thus, the heat dissipation effect between LBP is improved [18]. The simulation analysis results of the fin number of FHE between LBP are shown in fig. 2. When plotting this this figure, 300 W is also set as the standard for the heat dissipation performance of LBP, and different fins are used. The heat dissipation performance of the LBP under the number is compared with the standard value, and the influence of the number of fins on the heat dissipation performance of the LBP is measured.

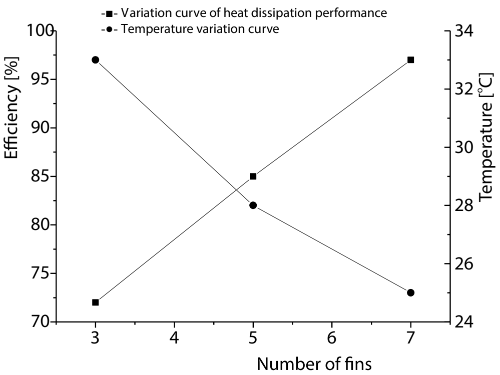

Figure 2. Simulation analysis of heat dissipation performance of LBP when the number of FHE changes

As shown in fig. 2, when the distance between the air intake area and the air inlet of the LBP is 6 cm, and when the lithium battery cells are distributed at equal intervals, the air intake speed between the LBP is 8 m/s. When the number of FHE is 7, the maximum temperature and temperature difference range that can be reached between the LBP are low, and the heat dissipation effect between the LBP is the optimal.

Simulation results of fin thickness changes of FHE

After the LBP are radiated through the FHE, the temperature between the LBP is also reduced to 24 °C, the temperature range of the lithium batteries during operation falls within a temperature range close to normal temperature. During the simulation analysis, the thickness of the FHE is increased to 2.5 mm. Due to the space limitation between the LBP, only a maximum of 6 FHE can be accommodated. Comparing the analysis results of this simulation with fig. 2, it is found that when the thickness of the FHE is 2.5 mm, and other conditions are consistent with the simulation parameters of the number of FHE, the maximum temperature of LBP has decreased, indicating that the thickness of the FHE has an effect on the heat dissipation efficiency between the LBP [19]. The results of the simulation analysis of the number and thickness of FHE between LBP are shown

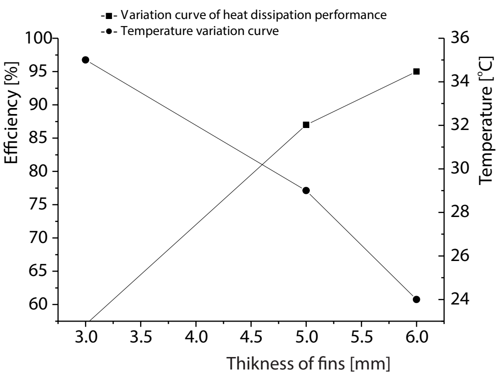

Figure 3. Simulation analysis of heat dissipation performance of LBP when the thickness of FHE is changed

in fig. 3. When plotting this figure, 300 W is also set as the standard for the heat dissipation performance of LBP, and different number of individual fins are utilized. The heat dissipation performance of the LBP under the fin thickness is compared with the standard value, and the influence of the thickness of the individual fin on the heat dissipation performance of the LBP is measured.

As shown in fig. 3, when the distance between the air intake area and the air inlet of the LBP is 6 cm, and the lithium battery cells are distributed at an equal distance, the air intake speed between the LBP is 8 m/s. When the number of FHE is six, and the thickness of the FHE is 2.5 mm, the maximum temperature and temperature difference range that can be reached between the LBP are low, and the heat dissipation effect between the LBP is the optimal.

Optimal heat dissipation scheme

Through the simulation analysis of the previous nine simplified heat dissipation OE schemes in the COMSOL Multiphysics software, the individual parameters, such as the air intake speed, the number of fins, and the thickness of the fins between the lithium batteries, are set in the software. The actual heat dissipation effects are simulated and analyzed through OE, and the results of several groups of experiments are compared. The results show that when the air intake speed between the LBP is 8 m/s, the number of fins is six, and the thickness of the fins is 2 mm, the heat dissipation effect of the LBP is the optimal. Therefore, this scheme in the OE is selected as the optimal heat dissipation scheme for this study.

Conclusion

In this study, COMSOL Multiphysics software is used as the simulation software to simulate the heat dissipation effect of the air intake speed, the number of fins, and the thickness of fins between LBP. Finally, OE obtains the optimal heat dissipation scheme for this study. In this study, the thermal management system of FHE is first selected. The objective is to improve the heat dissipation efficiency between LBP. Simulation analysis of the heat dissipation effect between LBP under single-factor changes in parameters, such as the air intake speed, the number of fins, and the thickness of fins between LBP, are performed. The simulation results show that under the single factor condition that when the air intake speed between the LBP is 8 m/s, the number of fins of the FHE is 7, and the individual fin thickness is 2.5 mm, the optimal heat dissipation result is obtained. Then, the simplified OE of L_9 (3^4) is performed for simulation analysis of these nine schemes. Finally, it is obtained that the heat dissipation effect of the LBP is the optimal when the air inlet speed between the LBP is 8 m/s, the number of fins is 6, and the thickness of the fins is 2 mm. Therefore, this set of test parameters is selected as the FHE performance optimization scheme of the LBP.

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