Study on Factors Affecting the Radiator-cooling of EV Power Battery Pack

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Abstract: Based on the battery pack cooled by cooling package within electric vehicle, the cooling process of the power battery was studied by simulation and tests. The influence of the pump speed and fan level on the battery cooling was compared. The results of the simulation and tests showed that the final battery temperature of the high fan level was lower than 1°C relative to the low fan level, while the impact of the high speed water pump relative to the low speed water pump is within 1°C during idle cooling procedure.

1 INTRODUCTION

Since the performance and reliability of the battery pack dependent on its temperature (Pesaran and. Keyser, 2001), various approaches to cool the power battery were studied (Zhang et al, 2015) (Rao and Wang, 2011). The liquid-cooled battery pack are chilled by a lower temperature coolant and are more efficient than air-cooled battery pack (Wu et al, 2002) (Chen et al, 2016). The coolant should be cooled down first before cooling the power batteries. Generally, coolant can be chilled by two methods (Wu W. 2019), one is cooled by the AC system of the vehicle with chiller, and the other is chilled by the ambient temperature with radiator. Chiller-cooling and radiator-cooling are combined in one architecture as illustrated in the Fig. 1.

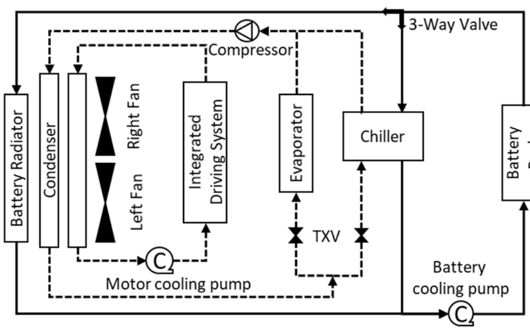

Figure 1: Electric vehicle thermal management system.

Many previous studies revealed the temperature spread within the battery pack (De et al, 2017) (Yoong,2019). But little attention was paid on the whole cooling structure. 1D and 3D simulation approaches were used to analyse the radiator cooling based on the whole cooling system in this paper.

There are two main factors influence the radiator-cooling efficiency (Deng Y. 2018), one is the fan speed, the other is the coolant pump working status. Different fan speeds and pump duty cycles were compared based on simulation and tests. The vehicle was in idle state, that is electrical loading on the battery pack was neglected, during the cooling process, so the self-heating of the battery was negligible.

2 CFD SIMULATION OF THE COOLING PACKAGE

The radiator was mounted in the front cooling package and coolant is cooled down by outside air flow, therefore the air flow caused by different fan levels should be analyzed by 3D CFD at first. The cooling package was arranged as shown in Fig.2.

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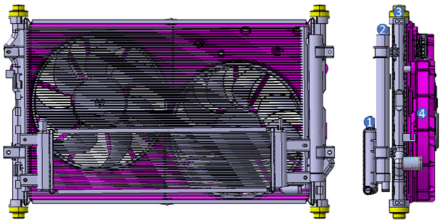


Figure 2: Cooling package arrangement.

The radiator dimensions were shown in Table1.

Table 1: Dimensions of the radiators.

Fan Levle	Width /mm	Height /mm	Thickness /mm
Battery Radiator	558	141	16
Condenser	657	356	16
Motor Radiator	716	440	16

The RPM settings of the high and low level of fan within the cooling package were shown in Table 2

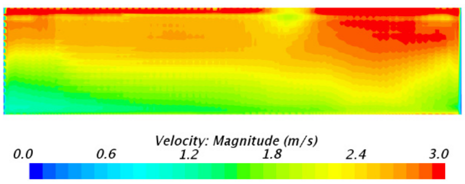
The air flow in the cooling package was supposed as incompressible. For CFD simulation, the following equations were used.

$$\mathrm{div}\bar{v} = 0 \tag{1}$$

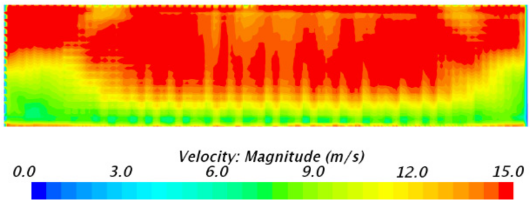
$$\mathrm{div}(\rho \bar{v} v_i - \mu_{eff}\, \mathrm{grad}\, v_i) = \frac{\partial p}{\partial x_i} + \mathrm{div}(\mu_{eff} \frac{\partial \bar{v}}{\partial x_i}) \tag{2}$$

$$\frac{\partial(\rho \mathrm{T})}{\partial T} + \mathrm{div}(\rho \bar{v} T) = \mathrm{div}(\frac{K}{C_p} \mathrm{grad}\, T) + S_T \tag{3}$$

The simulated velocity contour results of battery radiator by CFD is shown in Fig. 3



(a) Velocity contour of low fan level



(b) Velocity contour of high fan level

Figure 3: Velocity contour of battery radiator.

The 1D simulation model was built based on the thermal system illustrated in Fig.1. The coolant is 50%-50% glycol-water mixture. The flow resistance curve of the thermal system was simulated. The results were shown on Fig. 5

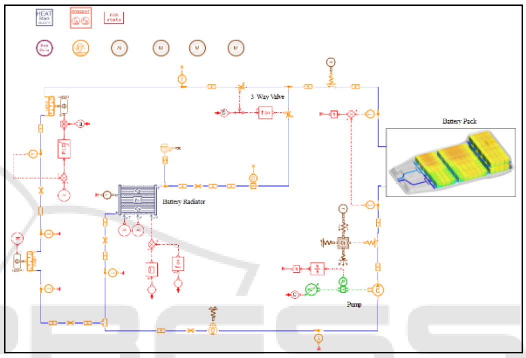


Figure 4: 1D simulation model of the thermal system.

The analysed work point was shown in Fig. 5.

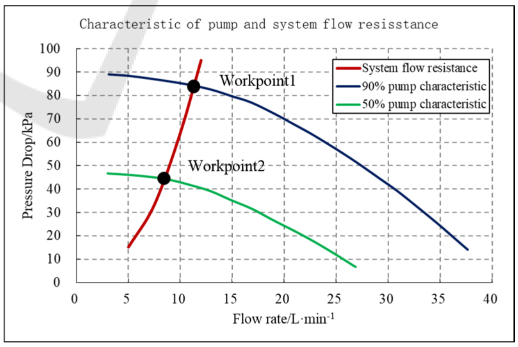


Figure 5: Pump characteristic and flow resistance curve.

Table 2: RPM of the fan on High/Low level.

Fan Level	RPM of Left Fan /rpm	RPM of Right Fan /rpm	Example column 1	Example column 2
Low	1750	1450	Example text 1	Example text 2
High	2550	2250		

Table 3: 1D simulation results of the thermal system.

Working point	Duty cycle /%	Pressure Drop /kPa	Flow rate / L·min-1	Pump Power /W
1	90	84	1450	56
2	50	44.5	2250	31

According to the above simulation, the pump power was 51W and 31W at 90% and 50% duty cycle, respectively. The detailed thermal flow system results were shown in Table 3.

3 SIMULATION OF BATTERY COOLING PROCES

The influence of the fan speed and pump duty cycle on battery cooling process were studied based on the previous simulated results. The simulation boundary conditions were listed in Table 4

Table 4: Simulation conditions.

Work Conditions	Ambient Temp. /°C	Initial Temp . /°C	Fan level	Pump Power /%
1	20	40	High	90
2	20	40	High	50
3	20	40	Low	90
4	20	40	Low	50

The heat transfer of the radiator can be calculated by NTU (Number of Transfer Units) (Theodore, 2011) method. The Heat transfer is calculated as followings.

$$kA = \frac{1}{\frac{d_1}{Nu_1\lambda_1 A_1} + \frac{1}{G_{wall}} + \frac{d_2}{Nu_2\lambda_2 A_2}} \quad (4)$$

kA is the total heat transfer coefficient, d is the hydraulic diameter, Nu is the nussel number, λ is the thermal conductivity of liquid, A is the heat transfer area, G_{wall} is the thermal conductivity of solid. The subscript represents gas-side and liquid-side fluids.

Battery loading was ignored, so there was no self-heating. The simulated coolant inlet temperature and average battery temperature was shown in Fig.6 and Fig.7

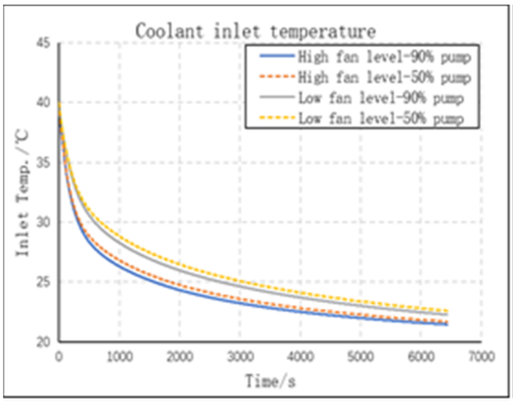


Figure 6: Coolant inlet temp. of simulation.

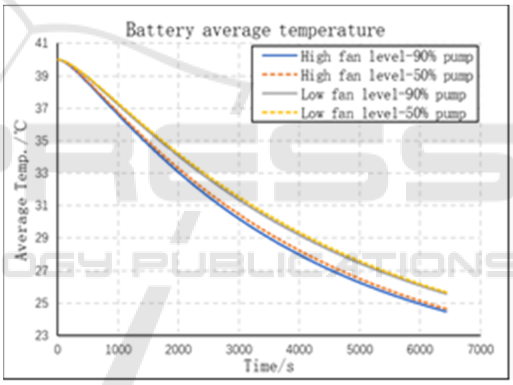


Figure 7: Battery average temp. of simulation.

According to the results, the effect of the fan level on the water temperature and average temperature of the battery was greater than the effect of the pump speed. High fan level can accelerate the water temperature and battery temperature drop under the same working conditions. In addition, the working power difference of the water pump was about 25W, while of the fan was about 317W.

4 TESTS OF BATTERY COOLING PROCESS

Cooling tests conditions were listed as Table 5.

Table 5: Test conditions.

Work Conditions	Ambient Temp. /°C	Initial Temp. /°C	Fan level	Pump Power /%
1	25	40	High	90
2	25	40	High	50
3	25	40	Low	90
4	25	40	Low	50

The test results temperature were shown in Fig.8 and Fig.9.

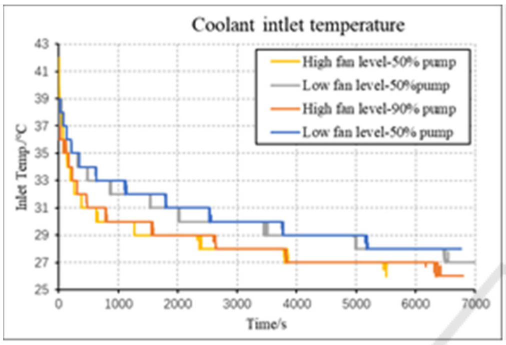


Figure 8: Coolant inlet temp. of simulation.

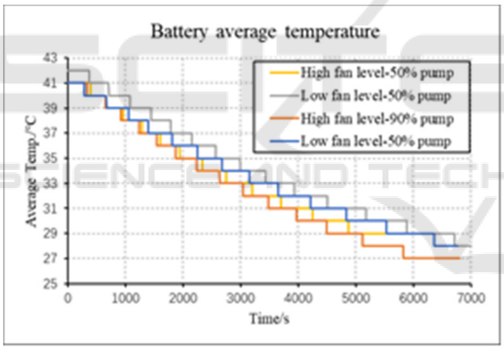


Figure 9: Cooling performance of test results under different fan and pump speed.

The comparison of the simulation and tests are shown in Fig. 10.

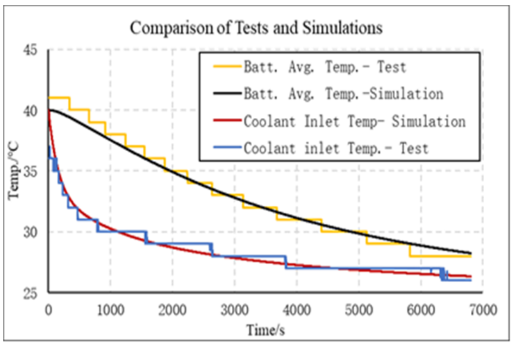


Figure 10: Coolant inlet temp. of simulation.

According to the comparison, the inlet temperature and the battery average temperature behaved the same, the simulation results were reliable.

5 CONCLUSIONS

This paper analyses the effect of water pump and fan on coolant temperature and battery temperature during the heat dissipation process. The results of the simulation and tests showed that the final battery temperature of the high fan level was lower than 1°C relative to the low fan level, while the impact of the high speed water pump relative to the low speed water pump is within 1°C during idle cooling procedure. The above analysis can be used to the battery cooling design.

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