Heat rejection efficiency research of new energy automobile radiators

W S Ma¹ and W X Shen² and L W Zhang²

1 Senior Production Editor, Hebei Jiaotong Vocational and Technical College, China
2 Production Assistant, Hebei Jiaotong Vocational and Technical College, China
E-mail: 595325836@qq.com

Abstract. The driving system of new energy vehicle has larger heat load than conventional engine. How to ensure the heat dissipation performance of the cooling system is the focus of the design of new energy vehicle thermal management system. In this paper, the heat dissipation efficiency of the radiator of the hybrid electric vehicle is taken as the research object, the heat dissipation efficiency of the radiator of the new energy vehicle is studied through the multi-working-condition enthalpy difference test. In this paper, the test method in the current standard QC/T 468-2010 "automobile radiator" is taken, but not limited to the test conditions specified in the standard, 5 types of automobile radiator are chosen, each of them is tested 20 times in simulated condition of different wind speed and engine inlet temperature. Finally, regression analysis is carried out for the test results, and regression equation describing the relationship of radiator heat dissipation, heat dissipation efficiency, air side flow rate, cooling medium velocity and inlet air temperature is obtained, and the influence rule is systematically discussed.

New energy vehicles refers to the fuel cell electric vehicle (FCEV), compressed natural gas (CNG) vehicles, hybrid vehicles (HEV) which use non conventional vehicle fuel as power resource, the advanced technology of power control and drive power source are integrated for vehicle manufacturing. The driving system of new energy vehicle has larger heat load than conventional engine. Compared with traditional fuel vehicles, new energy vehicles have small noise, less exhaust emissions and can effectively protect the environment. At the UN climate change conference in 2015, countries and regions including Germany, Britain, Holland, Norway and the 18 states of the United States formed "zero emission vehicle alliance", promising that by 2050, the state will no longer sell fuel cars. In 2016, the number of new energy vehicles in China was nearly 1 million 90 thousand (pure electric account for more than 60%), which accounted for half of the global electric vehicle. On one
hand, the new energy vehicles contain more power devices, has higher heat dissipation requirements; On the other hand, the new energy vehicle battery system for environment temperature requirements are more stringent, high or low temperature environment will significantly affect the vehicle mileage and battery life. Therefore, a higher requirement for the heat dissipation and heat dissipation efficiency of the new energy vehicle radiator is put forward.

In this paper, the heat dissipation efficiency of the radiator of the hybrid electric vehicle is taken as the research object, the heat dissipation efficiency of the radiator of the new energy vehicle is studied through the multi-working-condition enthalpy difference test. In this paper, the test method in the current standard QC/T 468-2010 "automobile radiator" is taken, but not limited to the test conditions specified in the standard, 5 types of automobile radiator are chosen, each of them is tested 20 times in simulated condition of different wind speed and engine inlet temperature. Finally, regression analysis is carried out for the test results, and regression equation describing the relationship of radiator heat dissipation, heat dissipation efficiency, air side flow rate, cooling medium velocity and inlet air temperature is obtained, and the influence rule is systematically discussed.

The heat dissipation efficiency of the radiator is the ratio of heat dissipation and heat absorption, the calculation method is shown as follows:

\[ Q_w = G_w \times C_{pw}(T_w1 - T_w2) \] (1.1)
\[ Q_w \] —— heat dissipation (kcal/hr)
\[ G_w \] —— flow rate (kg/hr).
\[ C_{pw} \] —— the specific heat of water (kcal/kg°C) = 1.0 kcal/kg°C
\[ T_w1 \] —— Enter water temp.(°C)
\[ T_w2 \] —— leaving water temp.(°C)

\[ Q_a = G_a \times S_{pa}(T_a1 - T_a2) \] (1.2)
\[ Q_a \] —— heat absorption (kcal/hr)
\[ G_a \] —— air flow rate (kg/hr)
\[ S_{pa} \] —— the specific heat of air (kcal/kg °C) = 0.24 kcal/kg °C
\[ T_a1 \] —— Inlet air temperature (°C)
\[ T_a2 \] —— Exit air temperature (°C).

Figure 1. Enthalpy difference test of radiator.
Figure 1 shows the radiator enthalpy difference test of a hybrid electric vehicle produced in Nanchang. The parameters of radiator enthalpy difference test mainly include 8 parameters, such as cooling medium velocity, air side flow, air side resistance and heat dissipation of the medium side. Table 1 shows the test result of the radiator with air side flow rate is 6000m$^3$/h.

**Table 1.** Test result of radiator sample 1 when air side flow rate is 6000m$^3$/h.

| Item                        | 1st group | 2nd group | 3rd group | 4th group | 5th group | 6th group | 7th group | Average value |
|-----------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------------|
| Indoor dry ball temperature (℃) | 25.03     | 25.06     | 25.08     | 25.09     | 25.08     | 25.07     | 25.06     | 25.07         |
| Indoor relative humidity (%) | 54.40     | 54.40     | 54.50     | 54.60     | 54.60     | 54.60     | 54.70     | 54.50         |
| Indoor atmospheric pressure (kPa) | 100.4     | 100.4     | 100.4     | 100.4     | 100.4     | 100.4     | 100.4     | 100.4         |
| Face wind speed of radiator (m/s) | 2.61      | 2.52      | 2.72      | 2.53      | 2.62      | 2.62      | 2.54      | 2.60          |
| Imported air density (kg/m$^3$) | 1.16      | 1.16      | 1.16      | 1.16      | 1.16      | 1.16      | 1.16      | 1.16          |
| Inlet air temp. (℃)          | 25.03     | 25.06     | 25.08     | 25.09     | 25.08     | 25.07     | 25.06     | 25.07         |
| Outlet air temp. (℃)         | 48.36     | 48.29     | 48.20     | 48.18     | 48.10     | 48.06     | 48.00     | 48.17         |
| Nozzle pressure difference(Pa) | 278.3     | 278.9     | 279.2     | 279.1     | 279.5     | 279.5     | 279.7     | 279.2         |
| Air resistance of radiator (Pa) | 249.0     | 249.2     | 249.4     | 249.7     | 249.8     | 249.9     | 250.0     | 249.6         |
| Inlet water temp. (℃)        | 69.96     | 69.85     | 69.79     | 69.74     | 69.70     | 69.68     | 69.67     | 69.77         |
| Backwater temperature (℃)    | 60.32     | 60.26     | 60.20     | 60.20     | 60.12     | 60.11     | 60.09     | 60.19         |
| Water side resistance of      | 33.4      | 33.5      | 33.4      | 33.5      | 33.6      | 33.6      | 33.5      | 33.5          |
After many experiments, we found that the influence parameters of the radiator dissipation efficiency of the hybrid electric vehicle are mainly three parameters: the air side flow rate, the cooling medium velocity and the inlet air temperature. In order to discuss the three parameters’ influence to the new energy vehicle radiator efficiency and heat dissipation, we will keep other parameters’ value constant, Separately, only change three key parameters’ value(change one parameter one time): the air side flow, cooling medium flow rate and inlet temperature in radiator enthalpy difference test, in order to get the influence law of three key parameters and the radiator heat dissipation efficiency.

### 1. Influence of air side flow

For the radiator, the main thermal resistance is the thermal resistance of the air side. Therefore, the air side flow has great influence on the radiator of automobile, while in the actual vehicle driving process, the air side flow of the radiator is the sum of vehicle speed, natural wind speed and fan speed. We first

| Parameter            | Value     | Value     | Value     | Value     | Value     | Value     | Value     | Value     |
|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| radiator(Pa)         | 2.3880    | 2.3940    | 2.3900    | 2.3920    | 2.3950    | 2.3920    | 2.3900    | 2.3920    |
| Volume flow(m³/hr)   |           |           |           |           |           |           |           |           |
| mass flow(kg/hr)     | 1381.0    | 1385.0    | 1383.0    | 1384.0    | 1387.0    | 1384.0    | 1389.0    | 1385.0    |
| Medium density(kg/m³)| 978.89    | 979.72    | 979.95    | 980.12    | 979.84    | 979.69    | 980.26    | 979.78    |
| Radiator fan current(A)| 0.00 | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| Radiator fan voltage(V)| 70.0 | 69.9      | 69.8      | 69.7      | 69.7      | 69.7      | 69.7      | 69.8      |
| Inlet and outlet temperature difference(℃)| 23.33 | 23.23 | 23.12 | 23.10 | 23.02 | 22.99 | 22.94 | 23.10 |
| Dielectric temperature difference℃| 9.63 | 9.60 | 9.59 | 9.54 | 9.59 | 9.57 | 9.58 | 9.58 |
| Air flow(m³/h)       | 5982.8    | 5988.4    | 5991.0    | 5990.1    | 5993.1    | 5992.4    | 5994.2    | 5990.3    |
| Medium flow(m³/h)    | 3.7990    | 3.8070    | 3.8000    | 3.8040    | 3.8110    | 3.8040    | 3.8070    | 3.8050    |
| Air side heat flow    | 42473.2   | 42337.3   | 42170.6   | 42123.7   | 42015.2   | 41960.0   | 41891.2   | 42138.7   |
| Medium side heat flow | 41631.7   | 41605.3   | 41529.4   | 41363.7   | 41602.5   | 41466.2   | 41538.8   | 41533.9   |
| Heat balance error(%)| 1.98      | 1.73      | 1.52      | 1.81      | 0.98      | 1.18      | 0.89      | 1.44      |
| Heat transfer coefficient(W/(M² °C))| 50.14 | 50.07 | 49.87 | 49.83 | 49.72 | 49.61 | 49.47 | 49.82 |

---

After many experiments, we found that the influence parameters of the radiator dissipation efficiency of the hybrid electric vehicle are mainly three parameters: the air side flow rate, the cooling medium velocity and the inlet air temperature. In order to discuss the three parameters’ influence to the new energy vehicle radiator efficiency and heat dissipation, we will keep other parameters’ value constant, Separately, only change three key parameters’ value(change one parameter one time): the air side flow, cooling medium flow rate and inlet temperature in radiator enthalpy difference test, in order to get the influence law of three key parameters and the radiator heat dissipation efficiency.

### 1. Influence of air side flow

For the radiator, the main thermal resistance is the thermal resistance of the air side. Therefore, the air side flow has great influence on the radiator of automobile, while in the actual vehicle driving process, the air side flow of the radiator is the sum of vehicle speed, natural wind speed and fan speed. We first
set the test condition as the inlet air temperature is 25 °C, cooling medium flow rate is 2.9 m³/h, the air side flow is 4000 m³/h, 4250 m³/h, 4500 m³/h, 4750 m³/h, 5000 m³/h, 5250 m³/h, 5500 m³/h, 5750 m³/h, 6000 m³/h in nine different conditions, the test results are shown in Table 2 (The data in the table for multiple measurements take the average value).

| Air side flow (m³/h) | 4000  | 4250  | 4500  | 4750  | 5000  | 5250  | 5500  | 5750  | 6000  |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Heat transfer coefficient (W/m²·°C) | 36.41 | 38.29 | 39.93 | 41.86 | 43.32 | 44.57 | 45.70 | 47.35 | 49.05 |
| Dissipate heat efficiency (%) | 37.1  | 36.0  | 34.7  | 33.5  | 32.5  | 31.7  | 30.9  | 30.3  | 29.7  |

The heat transfer coefficient (W/m²·°C) refers to the transferred heat of 1m thick material through the area of 1 square meters in 1 sec., under stable heat transfer condition, the temperature difference between the two sides of the surface is 1 degrees, the unit is W/m²·K (K can be replaced by °C here).

From Figure 2, it can be seen that with the increase of air flow, the heat transfer coefficient of the radiator increases significantly. This rule conforms to the common sense of the people. The increase of air speed will lead to the increase air volume fixed to the windward area per unit time, which will surely bring better cooling effect and increase the amount of heat dissipation. The regression equation of heat transfer coefficient and air side flow is \( y = 30.342 \ln(x) - 215.23 \), in which \( y \) indicates the heat transfer coefficient (W/m²), and \( x \) is the air flow (m³/h). In the statistical analysis process of variable
linear regression, use the least squares method to estimate parameters, R square regression is the ratio of regression square and sum deviate square, means the proportion of the sum deviate square which can be explained by sum regression square, the bigger the better, the more accurate model we can get. The value of R square is between 0–1, the closer to 1, the better the regression fitting effect we get, generally think that more than 0.8 of the model fit is better. The ratio of difference squared sums means that the ratio of sum of deviate squares which can be explained by the sum of squares of regression. The more the ratio is, the more accurate the model is, the more significant the regression effect is. While the selected index equation fitting regression equation of $R^2=0.9976$, means that the fitting degree is high, can meet the requirement.

![Figure 3](image.png)

**Figure 3.** Regression equation diagram of air side flow and heat dissipation efficiency.

As can be seen from Figure 3, with the increase of air side flow or air side flow rate, the heat dissipation efficiency of radiator decreases gradually, and with the increase of air flow rate, the trend of decreasing heat efficiency is more and more gentle. This is different from our regular impression. Mainly because with increasing air velocity, wind resistance power lead to the increase in energy consumption, so the ratio of heat increased by the air which flowing through heat radiator to the heat emitted by the medium in the radiator get bigger and bigger, cooling efficiency increases gradually, the regression equation of the phenomenon described as $y=-18.59\ln(x) +191.15$, where $y$ represents the cooling efficiency, $x$ represents said the air side flow. The $R^2$ is 99.3%, and the curve fitting is very high.

2. **Influence of flow velocity in cooling medium**

The flow velocity of the cooling medium of the automobile radiator has a great influence on the heat transfer coefficient and the heat dissipation efficiency of the automobile radiator system. When the other conditions are constant, increasing the flow rate of the cooling medium can increase the heat dissipation of the system. However, the increase in the flow rate of the cooling medium increases the power consumption of the pump. With the increase of the flow velocity of the cooling medium, the heat transfer efficiency of the radiator increases gradually, but the when the velocity of the cooling medium increase, the increase degree of the heat transfer efficiency gradually decreases.
Table 3. Velocity test data of different cooling medium of radiator.

| Velocity of the cooling medium (m³/h) | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 |
|--------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Heat transfer coefficient (W/m²°C)   | 37.44 | 40.86 | 44.38 | 47.69 | 50.62 | 54.91 | 58.70 | 60.57 | 62.38 |
| Heat dissipation efficiency (%)      | 33.8 | 36.7 | 39.2 | 40.9 | 41.2 | 42.9 | 44.1 | 44.9 | 45.5 |

As shown in Table 3, keep the inlet temperature of 25 °C, keep the air side flow 5000 m³/h, set coolant velocity as 3.0 m³/h, 3.5 m³/h, 4.0 m³/h, 4.5 m³/h, 5.0 m³/h, 5.5 m³/h, 6.0 m³/h, 6.5 m³/h, 7.0 m³/h nine kinds of conditions, the test results are shown in the following table (table data for repeated measurements of average value).

![Figure 4. Regression equation diagram of flow velocity and heat transfer coefficient of cooling medium.](image-url)
As can be seen from figures 4 and 5, the heat transfer coefficient and heat dissipation efficiency of the radiator increases with the increase of the flow velocity of the cooling medium. The heat transfer coefficient, that is, the increasing trend of the heat dissipation is in the linear law, and is approximately proportional to the flow velocity of the cooling medium. The regression equation has two times polynomial form, \( y = 6.491x + 18.38 \). The \( y \) shows the heat transfer coefficient, and the \( x \) is the cooling medium velocity, and the \( R^2 \) is 99.2%, the curve fitting is very high. The heat dissipation efficiency increases with the increase of the flow velocity of the cooling medium, but the increasing trend decreases gradually, and the regression equation has two times polynomial form, \( y = -0.534x^2 + 8.115x + 14.69 \), the \( y \) indicates the efficiency of heat dissipation, and the \( x \) is the flow rate of the cooling medium. The \( R^2 \) is 98.8%, and the curve fitting is very high.

3. Influence of air inlet temperature

The inlet temperature of the air side (cold fluid side) has a great influence on the heat dissipation of the radiator, and the bigger temperature difference between the cold and hot fluids means bigger heat dissipation. The inlet temperature of the radiator is very different during the different working conditions of the engine. So we set the radiator coolant flow as 2.9 m\(^3\)/h, air flow 5000 m\(^3\)/h, inlet air temperature was 25 °C, 26.5 °C, 28 °C, 29.5 °C, 31 °C, 32.5 °C, 34 °C, 35.5 °C and 37 °C, the test results are shown in the following table (the data in the table are repeatedly measured from the average value).

| Inlet air temperature (°C) | 25, 0 | 26.5, 5 | 28, 0 | 29, 5 | 31, 0 | 32, 5 | 34, 0 | 35, 5 | 37, 0 |
|--------------------------|-------|----------|-------|-------|-------|-------|-------|-------|-------|
| Heat transfer coefficient (W/m\(^2\)°C) | 43.32 | 42.72 | 42.07 | 41.50 | 41.42 | 40.17 | 38.24 | 38.15 | 37.25 |
| Heat dissipation efficiency (%) | 32.5 | 33.7 | 34.5 | 35.5 | 36.4 | 37.9 | 38.0 | 38.5 | 39.1 |

Through the test data of Table 4, it is easy to observe that with the increase of inlet air temperature,
the heat transfer coefficient and heat dissipation of automotive radiator are significantly reduced, but the heat dissipation efficiency is significantly increased. The air side (cold fluid side) entrance temperature has dual effects on the performance of the radiator: on the one hand, the air side entrance temperature decreases which increases the temperature difference between the cold and hot fluid, and improve the heat dissipating capacity of the radiator, but on the other hand, the air side entrance temperature reduces the heat exchange efficiency decreases.

![Figure 6](image6.png)

**Figure 6.** The regression equation diagram of the air inlet temperature and the heat transfer coefficient.

![Figure 7](image7.png)

**Figure 7.** Regression equation diagram of air inlet temperature and heat dissipation efficiency.

As can be seen from Figures 6 and 7, the heat transfer efficiency increases with the increase of the heat transfer coefficient of the radiator as the inlet temperature increases. The regression equation of the heat transfer coefficient (the dissipated heat) which changes with the inlet air temperature is $y = -0.017x^2 + 0.588x + 39.78$, where $y$ represents the heat transfer coefficient, and $X$ indicates the inlet air temperature. the $R^2$ is 96.8%, the curve fitting degree is very high. The heat dissipation efficiency increases with the increase of inlet air temperature, but the trend of increase decreases. The regression
equation has two polynomial form, \( y = -0.014x^2 + 1.449x + 5.433 \), where \( y \) represents heat dissipation efficiency, and \( x \) represents coolant flow. The R^2 is 99.7\%, and the curve fitting is very high.

A summary of the full text and suggestions for follow-up work:

This paper systematically discusses the influence of air side flow, cooling medium velocity and inlet air temperature on radiator heat dissipation and heat dissipation efficiency, so as to provide reference for the design of new energy vehicle radiator. At the same time, the regression equation is established on the basis of a relatively small amount of data collection. So the applicability of the new energy automotive radiator except air mixed cars also need further verification.
References

[1] Won J P and Lee K Thermal flow study on the integrated all aluminum radiator and condenser [J]. SAE 01-01-1756
[2] Ma H G Prediction method of performance about heat transfer and resistance performance for vehicle radiator [J]. Internal-combustion Engine Engineering 2002 23(l) p33-36
[3] Chen J A Research about heat dissipation performance of vehicle tube type radiator [J] Agricultural Machinery Journal 2000 31(3) p84-87
[4] Sahnoun A and Webb R L Prediction of heat transfer and friction for the louver fin geometry[J] Journal of Heat Transfer 1992 114 p893-900
[5] Davenport C J Correlation for heart transfer and flow friction for heart transfer and flow friction characteristics of louver fin [J] AICHE Symposium Series 1983 225 p19-27
[6] Chou J P The effect of the flow no uniformity on the sizing of the engine radiator [J] SAE 02-25-1980
[7] Wu L P Performance research of vehicle tube type radiator [J] Vehicle Engine 2005 156(2) P62-66
[8] Zhang X Z Simulation study of louver fin vehicle radiator simulation study Automobile Technology 2005(1) p7-10.
[9] Alvon E Double pass versus single-pass radiators for automotive application [J] SAE11-06-1989
[10] Amir J Mohanlnlad and Hosni H etc. Thermal fluid characteristics of an automotive radiator used as the exothermal heat exchanger in an auto air conditioning system[J] ASME 2005 Heat Transfer 4 p315-323
[11] Saidi M H and Mozafari A A Experimental study of thermal performance and pressure drop in compact heat exchanger installed in automotive[J] ASME 2006 Internal Combustion Engine Division Spring Technical Conf. p551-557
[12] Patrick H E Study of thermal performance in engine compartment[J] General Motor Aero/Thermal/Sealing Integration Center Report March1 2001
[13] Tamio K A Study for improving thermal effectiveness in automotive radiators [J] SAE 10-04-1994
[14] Zhu X and Liao Q. Analysis about flow resistance and heat transfer performance of tracked vehicle radiator [J] Journal of Chongqing University 2002(8) p40 -43
[15] Yu H Q and Wei Q Characteristic simulation of tracked vehicle radiator [J]. Tractor and Farm Transporter 2007(6) p68-70