Research on Calculation of Thermal Resistance of Water-Cooling Radiator of Cooling Tower of Thermal Power Plant Based on Fluid Software Fluent

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Abstract. This paper introduces the method of calculating the thermal resistance and thermal resistance of high-power water-cooled radiators in cooling towers of thermal power plants using computational fluid software (CDF) Fluent. By solving the three-dimensional unsteady flow field and thermal field, the thermal resistance and thermal resistance value of the water cooling radiator of the cooling tower of the thermal power plant under different flow rates are calculated, which provides the temperature calculation for the steady state and dynamic process of the high-power inverter in accordance with.

1. Introduction
The cooler is a type of heat exchanger, and the water-cooled multi-tube cooler is a cooler commonly used in electric power and hydraulic systems, and is also suitable for thermal power plant enterprises [1]. By using the cooler, two mediums with a certain temperature difference can realize heat exchange, so as to reduce the temperature and make the equipment operate normally. The internal structure of the water-cooled multi-tube cooler and the selection of external parameters have a significant impact on the heat exchange efficiency.

At present, in engineering applications, the structural design of water-cooled radiators is mostly empirical design. The actual heat dissipation effect is not ideal. The only measurement method is experiment. Factors such as inaccurate data. In order to improve power density, water cooling is usually used when using IGBT modules. In practice, water cooling radiators are often designed according to the structure, strength and installation requirements of IGBT modules. This paper first uses the empirical formula to theoretically calculate the thermal performance of the radiator, and then uses fluent software to simulate the heat dissipation process of a water-cooled radiator of a certain type of domestic electric locomotive. Analyse the simulated data to find out its existing structural defects. Finally, the corresponding experimental research was carried out and it was found that empirical calculation, numerical simulation and experiment coincided with each other, indicating that the combination of the three methods can better provide an important theoretical basis for the design and improvement of the radiator.

2. Calculation of heat resistance of radiator
The water-cooled radiator of the cooling tower of a thermal power plant refers to a device that uses high thermal conductivity materials to make a rectangular parallelepiped, and one or more threaded holes are
drilled on it to install heating crystals [2]. The most common is that the heat dissipation system composed of crystal and heat sink is placed perpendicular to the PCB, as shown in Figure 1:

![Diagram of water-cooled radiator of cooling tower in thermal power plant](image)

**Figure 1.** Assembly drawing of water-cooled radiator of cooling tower in thermal power plant

Referring to the above figure, we can draw the corresponding heat path diagram, as shown in Figure 2:

![Heat circuit diagram](image)

**Figure 2.** Heat circuit diagram

It can be seen from the above figure that the thermal resistance of the system is mainly composed of three parts $R_{jc}$. The thermal resistance of the internal heat source of the crystal to the transistor case $R_{jc}$; B. The contact thermal resistance of the transistor case to the radiator mounting surface $R_{ch}$;
Comprehensive thermal resistance $R_{ha}$. In these three parts, the thermal resistance $D$ in the crystal is determined by the manufacturer. We can’t do anything to change it, but we must know its precise size to facilitate the calculation of the thermal resistance in the future; the contact thermal resistance is only calculated by a simple formula $I_t$, its specific value with the contact pressure, the average roughness of the contact surface, and whether the contact is filled with materials with relatively high thermal conductivity can also be determined by some empirical data. Usually we are more concerned about the overall thermal resistance $R_{ha}$ from the radiator to the environment, and its calculation will be discussed in detail here [3].

According to the working thermal network diagram, the total thermal resistance $R$ of the system can be obtained by the following formula:

$$ R = R_{jc} + R_{ch} + R_{ha} $$

(1)

Among them:

$$ R_{ha} = R_d + \frac{R_c R_h}{R_c + R_h} $$

(2)

And so:

$$ R = R_{jc} + R_{ch} + R_d + \frac{R_c R_h}{R_c + R_h} $$

(3)

In the above formula, $R_{jc}$ can be known from the transistor book $R_{jc} = 2.0 \degree C/W$; $R_{ch}$ for the contact thermal resistance, its calculation formula is:

$$ R_{ch} = r / A $$

(4)

The high-power water-cooled radiator is usually composed of a copper substrate with a water channel inside, and its thermal resistance and thermal resistance are determined by the structure of the copper substrate and the amount of water flowing through the water channel. Due to the complex turbulent heat transfer process between the copper substrate and the cooling water, it is essentially a hydrodynamic problem involving fluid flow, fluid-solid heat exchange, and solid heat conduction. Therefore, the heat dissipation must be calculated more accurately the thermal resistance and thermal resistance of the device can be solved by the method of computational fluid dynamics. The steps are as follows:

1. Use Gambit to physically model the water-cooled radiator, define the solid area and fluid area in the model, and define the heat exchange area between solid and fluid.
2. Define the heat generation area of the radiator.
3. Define the boundary conditions of the fluid.
4. Use Gambit to mesh the calculation area and save the generated mesh file.
5. Read the saved grid file through Fluent and set the necessary parameters for the calculation of the material properties, boundary conditions, heat flux of fluid and solid.
6. Select the unsteady calculation mode, set the time step and time, start calculation, and save the calculation result of each step.
7. Calculate the temperature $T(t)$ of the radiator at each moment according to the calculation results, and calculate the thermal resistance of the radiator according to (2).
3. Numerical theoretical calculation

According to the empirical formulas of heat transfer and fluid mechanics, the temperature rise and flow resistance of the radiator are theoretically calculated. The thermal resistance and pressure drop of the radiator under various operating conditions are shown in Table 1.

| Flow rate (L / min) | Power dissipation 12kW | Thermal resistance (K / W) | Pressure drop (MPa) | Thermal resistance (K / W) | Pressure drop (MPa) |
|--------------------|-------------------------|----------------------------|---------------------|----------------------------|--------------------|
|                    |                         | Temperature rise (°C)      | Thermal resistance (K / W) | Pressure drop (MPa) | Thermal resistance (K / W) | Pressure drop (MPa) |
| 18                 | 16.7                    | 0.00139                    | 0.0011              |
| 22                 | 15.3                    | 0.00128                    | 0.012               |
| 26                 | 14.4                    | 0.00112                    | 0.015               |
| 30                 | 13.7                    | 0.00114                    | 0.02                |
| 35                 | 13                      | 0.00108                    | 0.0006              |

| Flow rate (L / min) | Dissipated power 16.8kW | Temperature rise (°C) | Thermal resistance (K / W) | Pressure drop (MPa) |
|--------------------|--------------------------|-----------------------|----------------------------|--------------------|
| 18                 | 23.3                     | 0.00139               | 0.011                      |
| 22                 | 21.4                     | 0.00127               | 0.012                      |
| 26                 | 20.1                     | 0.00112               | 0.015                      |
| 30                 | 19.1                     | 0.00114               | 0.02                       |
| 35                 | 18.2                     | 0.00108               | 0.0006                     |

3.1. Simulation calculation

Using the powerful 3D modeling function of Pro/E software, after solving the interface problem between CAD and CAE software, the model established in Pro/E is imported into Fluent’s pre-processing module Gambit. During the numerical simulation, the following reasonable assumptions are made about the model:

1. There are three heat dissipation methods for the radiator, namely heat conduction, convection heat exchange and heat radiation. Because the proportion of thermal radiation is very small, in this simulation, the effect of thermal radiation is ignored;

2. Air convection heat exchange only plays an auxiliary role in the entire radiator, so assuming that the air convection heat transfer coefficient is constant, its value is set to 10W / (K · m²) (according to heat transfer, the natural convection heat transfer coefficient of air is generally 5 ~ 20W / (K · m²));

3. It is assumed that the velocity of water at the inlet is evenly distributed, that is, the velocity and direction of each point in the inlet plane are the same;

4. Assuming that the parameters of the water flow at the outlet have stabilized, that is, the derivatives of the variables in the outlet plane are zero, and have no effect on the upstream flow ring;

5. The cooling fluid is water at normal temperature, which is treated as an incompressible normal physical fluid. Considering that the internal structure of the water-cooled radiator in this simulation is more complicated, Grid is used to divide the grid, and the unit form is tetrahedral unit, no-hadron unit and pyramid unit. The model is divided into about 1.3 million units. Through the inspection of the grid quality inspection tool in Gambit, the grid of the entire model is good and meets the calculation requirements. The total power dissipation of the radiator is 12kW and 16.8kW; the flow rate is 18 ~ 30L / min; the calculation turbulence model uses the standard k-ε model, the pressure-speed coupling uses the Simple algorithm, and the calculation convergence after 124 iterations [4].
3.2. Simulation results of cooling water flow and heat dissipation

Due to the complexity of the flow channel and the flow structure, it is difficult to fully express the flow structure of the cooling water in the entire flow channel, so the velocity distribution on the central cross-section (x-y plane) of the upper and lower layers of the flow channel are taken respectively. It can be seen from the simulation results that the overall flow velocity of the cooling water in the heat exchange channel is low. At the same time, it can be found that there is a “flow stagnation zone” with a very low flow velocity in the corner area on the fluid inlet and outlet sides, and this area has poor heat transfer. For the inlet side, due to the lower fluid temperature, the corresponding table temperature is also lower, and the effect of the flow stagnation zone is not significant; however, on the fluid outlet side, the fluid temperature gradually increases (under this condition, the fluid simulated value of the exit temperature is 50.8 °C), so the highest temperature of the device table appears in this area. Under this condition, the total pressure loss between the inlet and outlet of the cooling water is 16.81 kPa. Therefore, properly increasing the cooling water circulation flow can not only enhance the overall heat transfer performance of the radiator, but also make up for a certain resistance loss. In order to more clearly observe the flow structure in the flow channel, Figure 4 shows the velocity vector diagram of the flow channel cross section.

3.3. Simulation analysis of heat resistance change of radiator

(1) From the inlet to the outlet of the cooling water, through convection heat transfer, the heat transferred from the heat source is continuously absorbed along the way, and the water temperature rises; (2) At the
corner of the fifth and sixth row of channels, there is no channel. Across the entire heat flux area, the conduction heat resistance of the area near the heat source is large, resulting in a high temperature. This shows that there are certain defects in the structure of the heat sink. If the groove is lengthened, that is, the groove is spread over the IGBT heating area, the thermal resistance of the heat sink will be reduced [5]. When the flow rate is 30L/min and the total power dissipation is 16.8kW, the temperature rise of the radiator is 20 °C and the thermal resistance is 0.00119 °C/W. As the flow rate increases, the temperature rises and thermal resistance of the radiator decrease. When the total power dissipation is 12kW and 16.8kW, the thermal resistance curve of the radiator under different flow rates is shown in Figure 5.

![Heat Transfer Performance Vs. Number of Fins](image)

**Figure 5.** Heat resistance change curve of radiator

4. Conclusion
Using the powerful fluid heat transfer calculation function provided by Gambit and Fluent and the unsteady three-dimensional simulation calculation method, the thermal resistance and thermal resistance of the radiator under different geometric shapes, different heat dissipation media and different heat dissipation conditions can be easily calculated. The thermal resistance and thermal resistance of the heat sink can accurately calculate the junction temperature of the IGBT module die under dynamic conditions such as steady state and overload, fault, etc., thereby ensuring reliable and safe operation of the device.

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